WHITE AND RED PINE

Ecology Silviculture and Management

Canada
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WHITE AND RED PINE

Ecology
Silviculture
and
Management

by

K. W. Horton and G. H. D. Bedell

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PREFACE

This is a monograph dealing largely with the ecology and silviculture of eastern white pine (*Pinus strobus* L.) and red pine (*Pinus resinosa* Ait.), as single species and growing together as a forest type. The intended scope includes all subjects which influence pine management from a silvicultural viewpoint. Such fields as market economics, wood technology and utilization are not emphasized but are briefly considered when relevant.

The object is to provide a compendium of fundamental and applied knowledge as a reference for further research and for practical pine forestry. Previously such information was scattered in hundreds of diverse publications and unpublished reports.

While in many respects the technical coverage pertains to pine throughout its whole range, the emphasis is on pine in Canada, and particularly in the Great Lakes–St. Lawrence Forest Region where pine production is most important today.

In Canada white and red pine have almost identical ranges, occupy to a large extent similar sites, occur frequently in mixture, and are both of considerable economic interest; therefore it is expedient to deal with them in combination. This, then, is both a monograph of the white and red pine forest type and a comparative study of the two species.

It is almost wholly a literature review. With few exceptions, mostly involving widely accepted generalities, all the material is documented. The coverage is not strictly monographic. Many existing references to pine are too local and some too general in scope to warrant inclusion, but the attempt has been to include all published references of broad fundamental or particular technical interest. Some published information has been referred to indirectly through subsequent publications of a review or analytical nature. Apologies are offered for inadvertent omissions.

When the preparation of this bulletin first began several years ago, certain gaps in the available knowledge were found, to remedy which the Forest Research Division of the Forestry Branch undertook specific research projects. Their results have been published separately. Two of these publications, one dealing with pine ecology and the other with stand growth and yield have, with some revision, been included herein. Certain of the sections are to some extent reviews of previously published reviews. This applies to sections on artificial reproduction, intermediate cutting practices and pine entomology. The remaining parts constitute a general, up-to-date synopsis. Numerous contributors of source material who were instrumental in the preliminary preparation of this work are listed in the acknowledgement.

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ACKNOWLEDGEMENT

Many persons were involved more or less directly in the preparation of this bulletin, in planning and organizing it, in compiling data and references for preliminary write-ups, and in criticizing the text.

With the exception of the section on entomology and pathology, which was contributed by the Forest Biology Division of the Federal Department of Agriculture, the work was prepared by the Forestry Branch. Invaluable assistance through the provision of information and criticism was received from the Ontario Department of Lands and Forests, particularly the Division of Research of that Department.

Contributors of preliminary write-ups which provided much of the basis for the final presentation were as follows: pine historical occurrence—W. G. E. Brown; pine industry development and economics—G. C. Wilkes, H. M. Babcock; genetics—M. J. Holst; silvics—J. L. Farrar; mycorrhizal relationships—V. Slankis; ecology—W. G. E. Brown, K. T. Logan; silviculture—W. M. Stiell, R. J. McCormack; growth and yield—R. J. McCormack; entomology—L. M. Gardiner, L. A. Lyons, P. J. Pointing, C. R. Sullivan, J. B. Thomas, D. R. Wallace; pathology—L. T. White; specifications—Forest Products Laboratory of Canada, Canadian Lumbermen's Association.

Hundreds of references were reviewed and included, but particular reliance was upon the following: Hawley and Smith (1954), Hills (1954, 1959), McCormack (1956), Logan and Brown (1956), Brown and Lacate (1960), Horton and Brown (1960), Rudolf (1957), and Stiell (1959A, 1959B).

The cover drawing is by T. C. Brayshaw.

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PINE FOREST GEOGRAPHY

Ranges

The botanical ranges of white and red pine are shown on the map of eastern North America (Figure 1)[1]. In Canada, both species are concentrated in the Great Lakes–St. Lawrence and Acadian Forest Regions (Halliday 1937, Rowe 1959), but they extend north into the Boreal Forest Region and south well into the Deciduous Forest Region.

The primary limiting factor in pine distribution in the north is likely the short growing season; the range lines closely follow the 35° mean annual isotherm (Haddow 1948, Thomas 1953). Southward, where competing species are more numerous and diversified, the distribution of natural stands has always been more localized. White pine extends deep into the south along the Appalachian highlands, whereas red pine, except for a few minor outliers, is confined to the area of the last Pleistocene glaciation (Cook, Smith and Stone 1952).

The northern commercial range of both species at present corresponds reasonably closely with the northern boundary of the Great Lakes–St. Lawrence Forest. Beyond that the pines are too scattered to be of much significance. In the south the commercial range of red pine in particular has been extended through wide-scale planting.

Forest Associations

The two pines are so characteristic of the Great Lakes–St. Lawrence Region that it has been termed by some as the "Pine–Northern Hardwoods Region" and variations thereof (Nichols 1935, Braun 1950). Both white and red pine occur in pure stands here, and in diverse mixtures. Exploitation and ill-timed fires have tended to increase the proportion of mixed stands, but groves of pure pine remain frequent in some areas. Mixtures characteristic of the region involve, with the pines, sugar and red maple, beech, yellow birch, and hemlock and more locally, red oak, basswood, largetooth aspen, white elm and white cedar. From the north intrude the typically boreal species, white and black spruce, balsam fir, jack pine, trembling aspen, and white birch; from the east, red spruce.

In the Acadian Region the pines are present in most of the forest, although they have been greatly reduced by cutting and fire. Only rarely do pure stands occur today, usually in protected circumstances. Scattered pines, often old veterans, are to be found throughout the maple-beech stands of the upland areas, and the spruce-fir forests of the flatlands and coastal areas.

[1]The range lines in Canada are composed from "Native Trees of Canada" (Anon. 1956) and Haddow (1948). In the U.S.A. the red pine limits derive from Rudolf (1957), and the white pine from Munns (1938) and Harlow and Harrar (1941).


Figure 1
BOTANICAL RANGES OF WHITE AND RED PINE
Miles 100 50 0 50 100 150 200 Miles
LEGEND
Range limit of white pine
Range limit of red pine
Forest regions of Canada
Boreal
Great Lakes - St. Lawrence
Acadian
Deciduous
MAN.
ONTARIO
QUEBEC
JAMES BAY
NEWFOUNDLAND
PRINCE EDWARD ISLAND
NEW BRUNSWICK
NOVA SCOTIA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
L. ONTARIO
LAKE ERIE
MINN.
MICH.
WIS.
MICH.
IOWA
ILL.
IND.
OHIO
MO.
KY.
W.VA.
VA.
TENN.
N.C.
ARK.
MISS.
ALA.
GA.
SC.
PA.
N.Y.
N.J.
MD.
DEL.
MD.
VT.
N.H.
ME.
MASS.
CT.

Red and white pines occur sporadically in southern parts of the Boreal Region from Newfoundland to southeastern Manitoba, usually in isolated mixedwood stands or with jack pine on warm dry sites, surrounded by the more typical spruce-fir-aspen-white birch mixtures.

In the Deciduous Forest Region of southern Ontario white pine was once a fairly important component of many stands, but today in this highly cultivated area it remains abundant only on small areas of poor sandy soil together with oaks and other xerophytic species. In the central hardwoods region of the U.S.A., white pine occurs locally in mixture with a host of species in a variety of forest associations (Braun 1950) but is a dominant component mainly in areas transitional to the Hemlock-White Pine-Northern Hardwoods Region (the Great Lakes–St. Lawrence Region of Halliday).

Climate

The range of red and white pine in Canada and the U.S.A. involves a wide variation in climatic conditions. In Canada the climate varies from cold-dry in the southeastern Boreal Region in Manitoba, and cold-wet in Newfoundland, to warm-moist in the Maritimes and warm-dry in southern Ontario. The greatest pine concentration today is in the geographic centre of the area, in Ontario and southwestern Quebec (Horton and Brown 1960).

Selected climatic data (Anon. 1947) for this central pine area and the extremes for other parts of the pine range in Canada are as follows:—

Item	Pine Area	Extremes in Pine Range
Ann. average of daily mean temperature	40° F.	32 to 44°F.
Jan. average of daily min. temperature	−3° F.	−15 to 18° F.
July average of daily max. temperature	79° F.	64 to 81° F.
Average total precipitation	30.2″	20.3 to 53.1″

For the central pine area the data indicate a moderate temperature, but somewhat low precipitation. Summers are warm and somewhat droughty. The abundance of the pines in the various parts of the range is controlled to a large extent by climate as it favours or discourages competing species and the incidence of fires. However, the ability of the pines to grow in extremes of temperature and precipitation is noteworthy. The relative difference in climatic tolerance of the two pine species is evident in the fact that white pine ranges considerably farther southward, whereas red pine extends somewhat more northward in the cold-dry region of western Ontario. A more detailed account of climatic effects relating to pine on a local level is presented in the sections of this monograph on ecology.

Physiography

The pines grow on a wide range of soil conditions. Although they are most prevalent on terrace and outwash sand plains they are frequently found also on loams, silts, and clays of glacial tills and lacustrine deposits. In Canada their range extends for the most part over the Precambrian Shield, characterized by

Figure 2. Natural white and red pine stands in Eastern Canada. Above, a densely stocked pure stand of the two species. Below, a lightly stocked mixed stand of the pines, aspen, and other species.

an abundance of shallow, sandy soils on low, granitic knolls and ridges, frequently with narrow sand terraces between. In various parts of the Maritimes, southern Quebec, and southern Ontario, the rock formations are made up of richer sediments, and soil materials originating from these are accordingly finer and more fertile. The great soil group characteristically associated with the pines is a thin podzol, but under pine-mixedwood stands grey-brown podzolics, brown forests, and brown podzolics may be found, especially in southern Ontario. In the cooler-moister areas, humus podzols and iron-humus podzols may also occur. A more detailed description of the range of soil conditions associated with the pines in the central forest areas is contained in the ecological sections.

Post-glacial History

SUCCESSIONAL TRENDS

Since the last glaciation there have been periodic shifts in regional climate and, correspondingly, vegetation. The various forest species have been continually fluctuating in relative importance, according to studies of pollen stratigraphy by Potzger (1946, 1951, 1954, 1956), Terasmae (1959) and others. Dansereau (1953) puts forth several climatic theories to explain these changes with respect to the pine species and also broaches the possibility of shifts in specific ecological requirements over the ages. The evidence from pollen analyses is by no means complete, and the interpretations of past trends often conflict, but there is enough information to permit a reasonable conjecture of the history.

Following the glacial retreat in the area between Lake Superior and the prairie, the first trees to become established were evidently spruce and fir. They were subsequently invaded by jack pine, after which red and white pine became dominant. This development of the pines dates back to a comparatively warm period commencing between four and seven thousand years ago. At its peak a few hardwood species, notably oak and elm, obtained a foothold. Since that time a trend towards a cooler, moister climate has occurred, so that spruce, fir and jack pine have again become prevalent, relegating red and white pine to a minor position.

In the region of the Ottawa river the evolution of the forest since glaciation has apparently been somewhat more complicated. At first there was a relatively warm period associated in part with a marine invasion up the St. Lawrence valley, and the forest was dominated by jack pine, red oak and white birch. The climate became cooler after the sea retreated, and a spruce-fir forest followed. This may have coincided with the initial cool period and spruce-fir forest in the area west of Lake Superior. A general warming of the climate, associated with lower precipitation, promoted a transition to jack pine and then to red and white pine, with some xerophytic hardwoods. During this warm dry mid-period which ended about 3,000 years ago, white and red pine were likely major species from the Great Lakes and the St. Lawrence River northward well into the present Boreal Region. Their pollen has been reported as far north as latitude 51°. Hemlock and red pine became more abundant in the latter part of this period. Subsequently a moister climate evolved, encouraging first an invasion from the south of maple and beech, followed, as conditions became cooler, by yellow birch, spruce and fir.

PRESENT EFFECTS

There is evidence of a warming trend in climate in the past twenty or thirty years but this is considered a minor fluctuation compared with the general

Figure 3. Hewing white pine square timber with a broadaxe.

Figure 4. Rafts of square timbers at Ottawa, 1898.

cooling period which has prevailed during the last several centuries. This cooling period followed the warm mid-period when white and red pine, and then maple and yellow birch, extended well into the Boreal Region. As a result these species are now confined to the warmer sites in this region, surrounded by boreal forest, mainly of spruce, fir and white birch. Moreover, it is thought that at least until recently the boreal line has been extending southwards, causing the wane of the non-boreal species such as white and red pine.

Many of the present white and red pine stands thus represent edaphic or pyric relics on warm, dry sites. Generally, the climatic conditions are against the maintenance of these species as major forest components. These facts should be considered in forest management if pine reproduction is an objective. Cutting methods which encourage the development of competitors more favoured by the present climate will combine with natural succession to exclude pine from the forests.

ECONOMIC HISTORY IN CANADA

The lumber industry in Canada and the U.S.A. was founded upon white pine three centuries ago. Pine products, timber, lumber and roundwood, have always been highly prized. Pine resources have always been relatively accessible. Thus from the first it has supported a thriving industry, and the supply of merchantable material has dwindled.

Industrial Development

The earliest significant use of pine in Canada was in the St. Lawrence valley at the time of the French Regime, when a small export trade in pine ship masts developed. There was always some local lumber trade in the colonial economy, but it was under British rule, about the beginning of the 19th century, that a timber trade began in earnest, with the export of pine timbers to Britain (Fauteux 1927).

As the 19th century progressed there was a great expansion in pine lumbering. The industry moved gradually westward—from the St. Lawrence region across western Quebec and Ontario; and concurrently from New England across New York to the Lake States. A vigorous trade in square timber developed between Canada and Britain. Toward the end of this expansion period the great tracts of virgin pine timber became sparse and lumbermen were forced to retrace their steps and utilize by-passed stands. The large trees needed for square timber became scarce and the demand declined so that, in the 1870's, sawn lumber came to the fore, with its market mainly the United States.

Production Trends

About the time of Confederation in Canada, statistics on pine production became available, allowing a graphic portrayal of trends. There was great activity in lumbering during the decades around 1900. Pine lumber production reached a peak in Quebec about 1890, and in Ontario about 1907 (Table 1). Then from 1910 production declined rapidly and steadily as the supply of merchantable timber diminished. Many of the mills closed and were supplanted by smaller, portable mills which were better adapted to utilize the smaller timber and leftover stands.

FIGURE 5 - COMPARATIVE ANNUAL PRODUCTION OF WHITE AND RED PINE LUMBER IN ONTARIO AND QUEBEC

SELECTED PERIODS 1908 to 1955

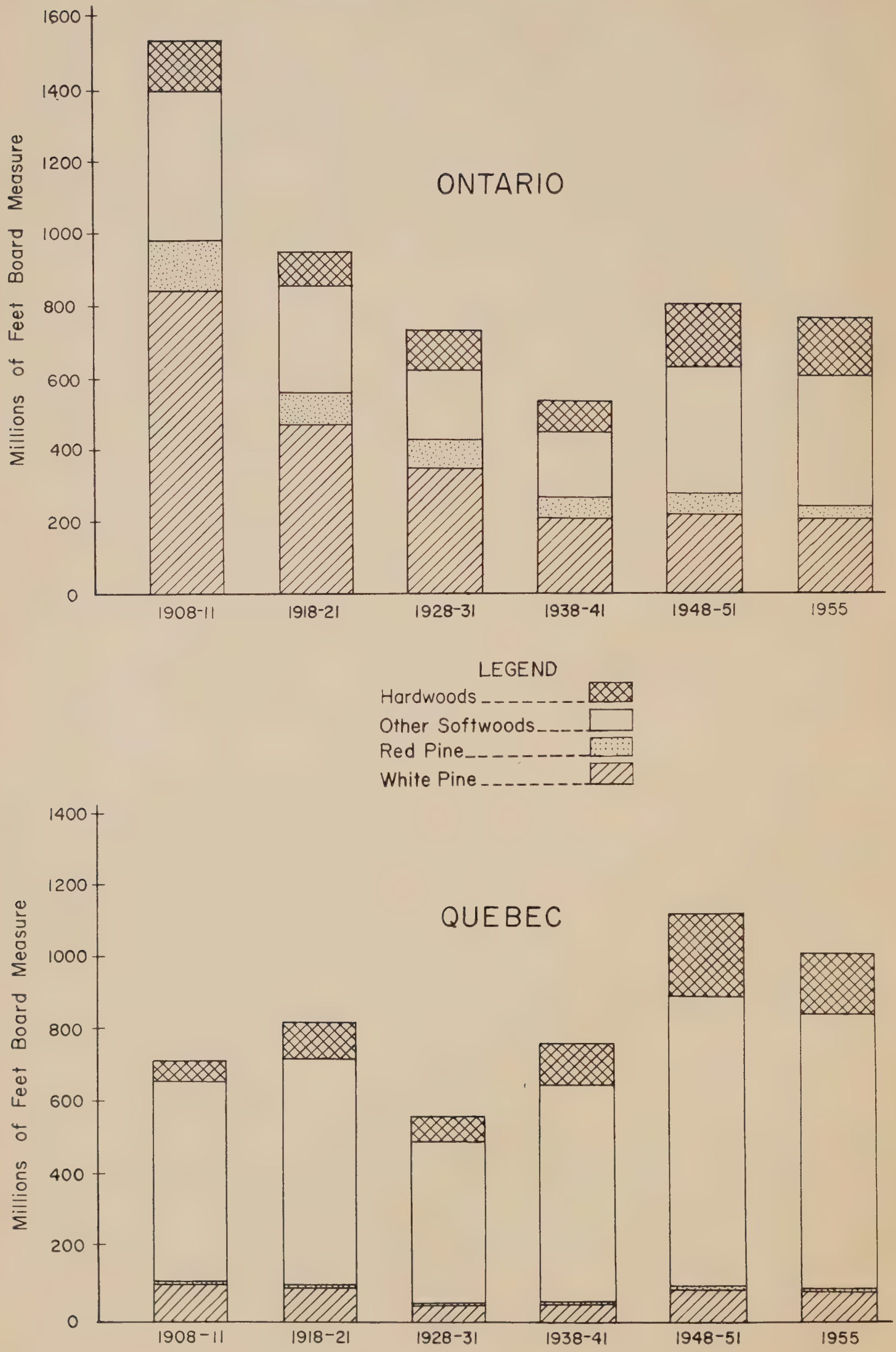

Table 1.—Volumes of White and Red Pine Timber Cut on Crown Lands

Quebec[1]			Ontario[2]	
Date	Sawlogs (million ft. b.m. log scale)	Square Timber (M. cu. ft.)	Date	Sawlogs (million ft. b.m. log scale)
1867	152	4,893	1867	161
1870	222	3,983		
1880	247	1,596	1877	330
1890	305	3,146	1887	629
1895	207	1,444	1897	528
1901	107	636	1907	790

[1]Defebaugh (1906)
[2]Hipel *et al.* (1943)

Table 2.—Accessible Volume of Softwood Standing Timber, 1958
(millions of cubic feet)

Sawlog Size (10″ + d.b.h.)	Nova Scotia	New Brunswick	Quebec	Ontario
White Pine	249	323	188	2,017
Red Pine	16	21	40	576
Subtotal	265	344	228	2,593
Other Softwoods	1,340	3,955	6,807	13,548
Total Softwoods	1,605	4,299	7,035	16,141
White and Red Pine as a % of Total	16.5	8.0	3.2	16.1
All timber (4″ + d.b.h.)				
White Pine	314	385	887	2,504
Red Pine	26	45	222	750
Subtotal	340	430	1,109	3,254
Other Softwoods	4,492	11,517	43,130	50,182
Total Softwoods	4,832	11,947	44,239	53,436
White and Red Pine as a % of Total	7.0	3.6	2.5	6.1

Present Resources

The supply of merchantable white and red pine in Ontario and Quebec, the major pine producing provinces, is certainly lower today than it was around the turn of the century when the production rate was so high, but it has remained reasonably stable for over 30 years (see Table 1 and Figure 5). Inventory data are given in Table 2. It is apparent that other softwood timber species, particularly spruce, fir, and jack pine, over-ride white and red pine in importance. Pine (white and red) four inches d.b.h. and over comprise only 2.5 per cent of all accessible softwoods in Quebec and 6.1 per cent in Ontario. Pine of sawlog size constitutes 3.2 per cent of the accessible total in Quebec and 16.1 per cent in

Ontario. Nevertheless the value of pine lumber production is appreciable. In 1955 Ontario produced $58,654,000 worth of lumber of which 32.3 per cent was white and red pine, and Quebec produced $69,546,000, 10.7 per cent being pine (Anon. 1956).

The total resource value of pine is by no means wholly reflected in these figures. Red and white pine are being used more than any other lumber species in reforestation, and the potential value of the young stands, particularly plantations, is great.

Supplies of the two pines are limited in other Canadian provinces but are appreciable in parts of the U.S.A. In the 12 Northeastern States there are about 5 million acres of white and red pine in a total of 73 million acres of commercial forest land (Anon. 1958).

Markets

White pine wood possesses qualities which are always in demand. Its even texture, softness and general workability have made it a renowned species throughout the domestic and overseas lumber trade. Red pine makes excellent construction lumber and polewood. Details on the properties and uses of both species are given in other Forestry Branch publications (Anon. 1951), and forest products specifications are shown in Appendix III. Recently, other markets have evolved which permit the utilization of smaller trees from intermediate cuttings—Christmas trees and pulpwood.

Thus the markets for pine products are sound and diversified. It has been pointed out that the potential lumber market for eastern white pine in the U.S.A. is several times greater than the current annual production of about one billion board feet (Lockard 1959). To realize any increase in markets, and even to retain the *status quo* in competition with alternative species and materials, it is essential that both the quantity and quality of pine timber be improved. The primary challenge therefore is to silviculture.

SILVICS

Morphology

Reference is made to "Native Trees of Canada" (Anon. 1956) and other dendrological works for detailed particulars on the morphological characteristics of the two pines. For convenience the salient features are outlined below. They are illustrated in Figures 6 and 7.

White pine under optimum conditions may attain a height of 175 feet and a diameter of 5 feet[2], but the usual dimensions at maturity are 100 feet in height and 2 to 3 feet in diameter (breast height). Its greyish bark is smooth on young stems but rough and deeply furrowed on old trunks. The cones are cylindrical, 3 to 8 inches long and often slightly curved. They open at maturity and fall shortly afterwards. Needles are in bundles of 5, and are $2\frac{1}{2}$ to $5\frac{1}{2}$ inches long.

Red pine generally reaches a height of 75 to 125 feet and a diameter of 1 to 3 feet, although trees 150 feet high have been recorded (Sargent 1897). Its bark is reddish, scaly when young, becoming furrowed with broad scaly plates when older. The cones are ovoid, $1\frac{1}{2}$ to $2\frac{1}{2}$ inches long, with scales thickened at the tips and spineless; they open at maturity but persist on the tree until the following spring. Needles occur in bundles of 2 and are notably long, $4\frac{1}{2}$ to $6\frac{1}{2}$ inches.

[2]Records of trees up to 260 feet high and 20 feet in girth are cited in Dallimore and Jackson (1948).

Figure 6. Eastern White Pine, *Pinus strobus* L.

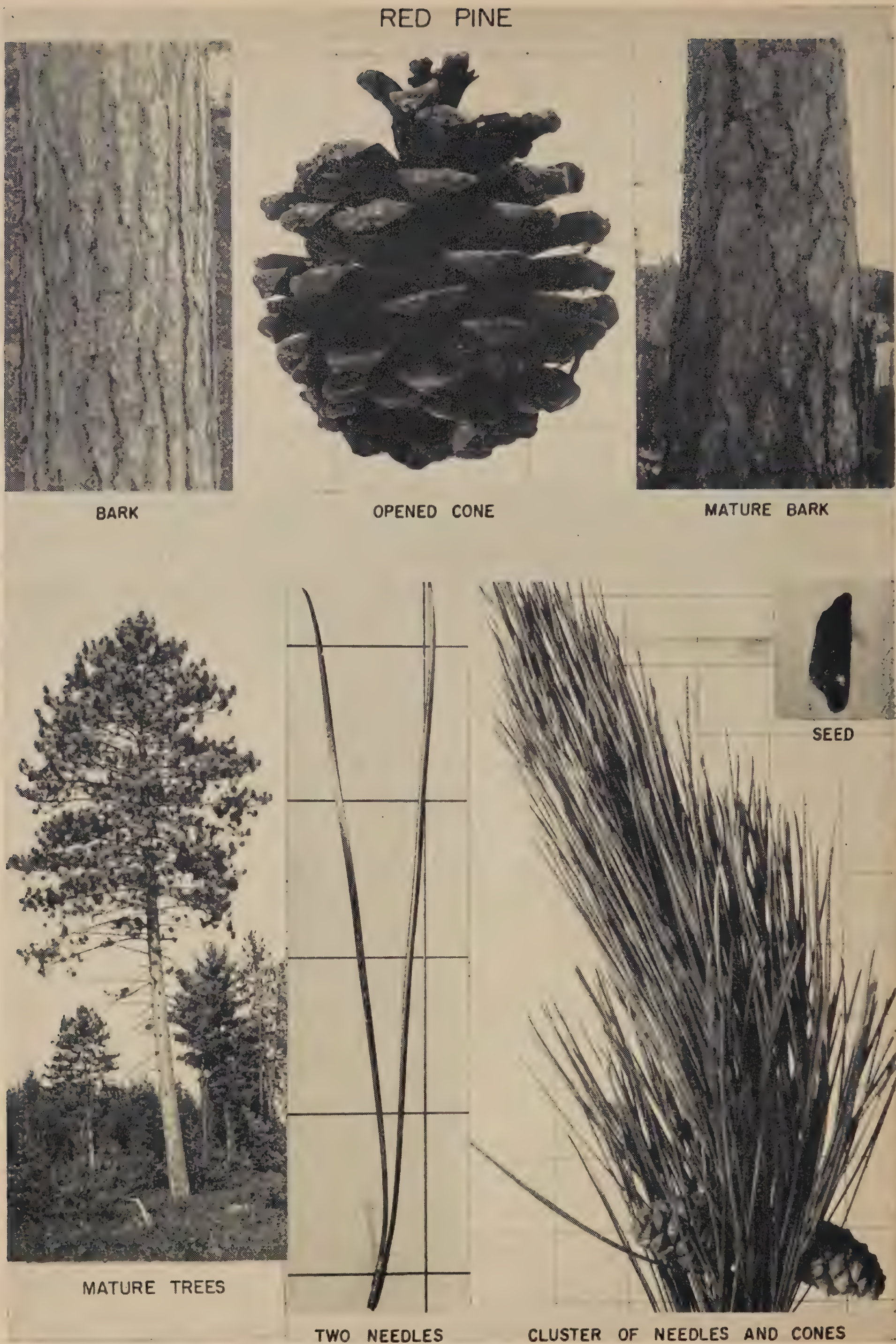

Figure 7. Red pine, *Pinus resinosa* Ait.

The two pines each have characteristic crown shapes which permit instant identification. White pine crowns appear ragged and irregular because of the long, heavy, isolated, horizontal branches. Often the trunk is crooked or forked through weevilling. Red pine crowns present a more symmetrical, oval or pyramidal outline, and are more uniform and dense. In both cases the crown tops flatten with age.

Genetics

INTRA-SPECIFIC VARIATION

Intra-specific variation on a taxonomic level is insignificant in white and red pine. Little (1953) lists a *Pinus strobus* var. *chiapensis* Martinez, occurring in southern Mexico and Guatemala, far removed from the main specific range. Several horticultural varieties are mentioned in Dallimore and Jackson (1948), but none are important. They are: var. *aurea* (yellowish leaves), var. *monophylla* Tubeuf (cohering leaves), var. *nana* Knight (dwarf form), var. *nivea* Booth and Knight (short, silvery leaves), and var. *prostrata* (prostrate habit).

Red pine has only one horticultural variety, namely *P. r. globosa* Rehd., a dwarfish, dense form of globose habit.

Provenance

Hereditary variations in performance connected with provenance do exist, however. These are shown by provenance experiments, in which plants originating from natural stands in a variety of locations are compared for growth rate, form, winter hardiness, disease and insect resistance, and timber quality.

Comprehensive red pine provenance experiments started in the 1930's in the northern U.S.A. indicate that distinct racial differences exist. Rudolf (1947, 1949), reporting on a test plantation in northeastern Minnesota, found local races best, followed by races from near-by Minnesota and Wisconsin localities. More distant provenances, particularly from New England, lower Michigan, and central Wisconsin, showed much poorer growth and greater susceptibility to winter frost injury. Likewise in northern Wisconsin, trees raised from Pennsylvania and New England seed suffered extensive winter killing (Anon. 1930). In a Pennsylvania test plantation, many Lake States races proved superior to all New England races, yet others were the poorest of all races tested (Hough 1952A).

Of the northeastern races tested, the New York was better than the Pennsylvania, and the Massachusetts and Maine were poorer. The Maine source was also poorer than some from West Virginia (Buell 1940). Ontario provenances were included in a test in New York State, and one from Massey outshone all others and differed from local sources as well. However, at the Petawawa Forest Experiment Station, Chalk River, Ontario, the Massey source has been inferior to local and more southern sources in a young plantation. To investigate this complex matter further there are at present about 50 varied seed sources on trial throughout the red pine range in Canada.

Provenance tests of white pine are few but indicate the same sort of variation. One in Massachusetts, involving 42 seed lots, showed decreasing quality in plants from increasingly remote sources (Pauley *et al.* 1955). Another limited test involving several of the same sources plus others from Quebec and Ontario is located at Chalk River, Ontario. After 12 years the sources from New

Hampshire and Massachusetts were almost one foot higher than Canadian sources, but were coarser in branching and more prone to weevilling. In 1951 the Ontario Department of Lands and Forests in co-operation with the Federal Forestry Branch established a large-scale provenance trial involving 24 seed sources in 10 test plantations scattered through southern and central Ontario and Quebec, but data are not yet available.

Thus there is great variation in specific performance between sources from different zones, and considerable within a zone. Early results from provenance tests may be misleading, since the initial seedling size is largely determined by seed size (Hough 1952, Pauley *et al.* 1955), and seed of southern origin is generally larger and higher in germinating per cent (Bates 1930). Until more is known it is safest to use only seed of local origin for the establishment of plantations.

INTER-SPECIFIC VARIATION

Hybridization between similar species provides another source of variation, with practical ramifications in tree breeding, particularly for the improvement of growth qualities and of resistance to adverse agents. Extensive pine breeding programmes are underway in Canada at the Southern Experiment Station, Maple, Ontario, at the Petawawa Forest Experiment Station, Chalk River, Ontario, and at several locations in the U.S.A.

Breeding Red Pine

Red pine inter-specific hybridization, either natural or artificial, has not been reported so far, although several attempts to produce it have been made. Holst and Heimburger (1955) discuss the possibilities of using the resistant *P. thunbergii* and *P. nigra* var. *austriaca* to improve the resistance of *P. resinosa* to the European pine shoot moth, and of using *P. densiflora* as a link in breeding otherwise incompatible species.

Breeding White Pine

White pine has proven more amenable to breeding and has been successfully crossed with several species (Richens 1945). The latest complete descriptions of hybridizations attempted and achieved in the white pine group are in Schutt (1959). Of 11 different species combinations obtained among the white pine group by the Northeast Forest Experiment Station (Anon. 1955), the following were especially interesting in view of rapid growth:

P. griffithii × *P. strobus*
P. strobus × *P. griffithii*
P. strobus × *P. ayacahuite*

Suggestions of hybrid vigour were noted in crosses of *P. monticola* × *P. strobus* at Spokane, Washington (Bingham *et al.* 1956), and in one cross of *P. strobus* with *P. excelsa* in Europe (Meyer 1954).

Breeding strains resistant to blister rust (*Cronartium ribicola* Fischer) is the foremost problem, and encouraging leads have been found. *P. strobus* grafts are probably less susceptible to rust than are seedlings (Heimburger 1955) but *P. peuce* grafts and seedlings are significantly less susceptible than either of the *P. strobus* sources. Rust resistance has been successfully transmitted to hybrids through controlled pollinations between resistant selections of parent species.

This was achieved with crosses of *P. monticola* and *P. strobus* (Bingham *et al.* 1956) and of *P. strobus* and *P. excelsa* (Meyer 1954). *P. monticola* also shows resistance towards the white pine weevil (*Pissodes strobi* Peck), and promising resistant hybrids between it and *P. strobus* have been reported (Gabriel 1958). Moreover there is a good chance that certain hybrid strains of *P. peuce* × *P. strobus* will, when backcrossed with *P. strobus*, transmit resistance to both weevil and rust damage (Fowler and Heimburger 1958).

Thus the possibilities of improving pine plantation stock through the breeding of superior and resistant strains and crosses are ever expanding. It is important that the knowledge already available be practised. A summary of the available knowledge of genetical features of various white pine species which may be useful in breeding has been presented in discussion by Heimburger (Anon. 1956). Breeding for resistance to weevil has been recently synopsized by Wright and Gabriel (1959). A convenient guide for selecting superior pine forest stands and trees is already available (Rudolf 1956). It considers such points as growth rate, form, resistance, wood quality, seed production and tolerance—all important in breeding.

Flowering and Fruiting

Pines are monoecious—both male and female flowers occur on the same tree. The male flowers develop in groups around the base of moderately vigorous twigs, and the female near the end of more vigorous twigs, usually towards the crown tips.

The flower primordia in red pine are initiated in July of the year preceding flowering and the same probably holds for white pine. In Ontario, the male flowers first become visible late in May (Figures 8 and 9), the female following two weeks later. Red pine flowers of both sexes are purplish in colour, whereas those of white pine are, appropriately enough, yellowish-white.

Pollination occurs about the first of June in red pine, and about mid-June in white. The ovule-bearing scales of the female flowers flex open a day or two afterwards, remain so for about a week, then close, entrapping pollen grains. These grow in the ovules; but in red pine fertilization does not take place until July of the following year, when cones are fully developed and hardened. (Ferguson 1904, Lyons 1956).

The female flowers develop into small green conelets. By the end of the first growing season the red pine conelet is round and about ½ inch in diameter, while the white pine is elongated, about ½ inch long (Figures 10 and 11). During the following year they develop rapidly and in both species usually ripen about mid-September. In the ripening process the green cones turn to purple and then brown in red pine, and to yellowish-green and brown in white pine. Natural dispersal of seed occurs only when the cones are brown, although most red pine seeds are viable during the transition from purple to brown (Rudolf 1940). White pine cones fall shortly after seed dispersal, but red pine cones usually remain on the tree until the spring or sometimes a year or two later. A few seeds may remain overwinter in these cases.

Seed Production

age effects

Planted pines can produce female flowers as early as 5 years of age, and male flowers at 9 years (Righter 1939). Viable seed has been recorded on 12-year-old

red pines only 8 to 10 feet tall (Roe 1945). However, seed production normally begins later, covering the spans shown in Table 3. This varies with density in red pine, beginning at 20 to 25 years in open conditions, and at 50 to 60 years in closed stands (Woolsey and Chapman 1914).

Table 3.—Seed Production of White and Red Pine[1]

	Seed-bearing Age (years)			Seed-year Frequency (years)		Yield of Cleaned Seed (no. per pound)			Ounces per Bushel of Cones	No. of Closed Cones per Bushel
	Min.	Opt.	Max.	Good crop	Light crop	Low	Average	High		
White Pine	15–20	50–150	250	3–5	Most intervening	20,000	27,000	53,000	5–28	500–700
Red Pine	25	50–150	200+	3–7	Most intervening	30,000	52,000	71,000	9–12	1,300–1,800

[1]Data from the "Woody-Plant Seed Manual", 1948.

CROP FREQUENCY

The seed-year intervals of each species are also given in Table 3. It is noteworthy that good red pine crops are a year or two less frequent than white pine. Bumper crops of red pine appear only once every 10 or 12 years (Conzet 1913). As a result of this inferiority in seeding, red pine has received more attention in seed research than white.

CONE PRODUCTIVITY

The seeds occur in pairs on the upper surface of the cone scales, but only scales in the central half of the cone bear viable seed. Even in that central part the proportion of abortive seed in red pine is seldom less than 20 per cent and may amount to 100 per cent (Lyons 1956). The germination per cent of sound seed usually averages 75 in red pine and slightly less in white (Anon. 1947).

There are usually from 14 to 45 seeds per normal red pine cone, averaging about 20 (Rudolf 1940, Lyons 1956). Long cones are more productive of good seed than short, cones of the upper third of the crown more so than those below, and cones borne on main branches at each crown level more so than those borne on laterals (Lyons 1956). Yields of cones and seed by weight and volume are shown in Table 3. The figures represent cleaned, dewinged seed. Uncleaned seed will contain many unfilled ones and the number per pound will consequently be higher.

STAND PRODUCTIVITY

In a red pine stand at the Petawawa Forest Experiment Station it was observed that trees of larger diameters (hence greater crown surface) produced most of the cone crop, and suppressed trees virtually none of it. A similar tendency has been recorded in a white pine stand (Messer 1956). Stand density also greatly affects the cone production. For example, during a good seed year mature open-grown trees have produced 725 cones, and trees in a medium-stocked stand only 200 cones (Conzet 1913). In over-stocked conditions the production will be negligible (Fraser 1951).

Figure 8. Red pine—male flowers, immature cone, and young vegetative shoots.

Figure 9. Male flowers of white pine.

Figure 10. Immature cones of red pine.

Figure 11. Immature cones of white pine.

The seedfall is generally inadequate in the intervening years between good crops. There is, however, a possibility of inducing cone production by partial girdling (Drinkwater 1958) and by the application of fertilizers on the ground (Holst 1959). In a moderately heavy seed year, medium-stocked mature red pine stands have produced from 75,000 to 110,000 seeds per acre (Shirley 1933), and in a bumper seed year, a seedfall of up to 350,000 per acre has been recorded (Cayford 1958). Another variable in stand seed production is inherent capacity. Some trees in a stand may be consistently good and others consistently poor cone producers (Conzet 1913). Still another variable is stand age structure. It is recorded that a 90-year-old stand of white pine produced five times the cone crop of a comparable 60-year stand, (Messer 1956).

EXTERNAL LIMITING FACTORS

All told, from year to year and from place to place there is great variation in the seed crop. Apart from the physiological functions, such external influences as weather and cone insect and rodent populations can greatly vary the crop, locally or regionally. Frost and drought may affect flowering. Prolonged rainy weather during pollination may greatly reduce the seed set (Anon. 1948). Various fauna may reduce the cone and seed production. Cone-boring beetles and worms such as the red pine cone beetle (*Conophthorus resinosae*) deform and often destroy the cones (see page 145). Squirrels, particularly the red squirrel (*Tamiasciurus hudsonicus*), may partially or completely destroy both the current and succeeding year's seed crops by cutting off the cones or the cone-bearing branch tips (Cheney 1929, Roe 1948). Finally, chipmunks, mice, and birds of the sparrow family may consume a large part of the seed that reaches the ground (Shirley 1933, Eyre and Zehngraff 1948).

Dissemination

The distribution of seed trees in relation to pollination range is an important consideration in forest seeding. Both pines can be self-pollinated but the progeny is inferior to that resulting from cross pollination (Johnson 1945). It has been found that pollen of some pine species will disseminate effectively only 100 to 200 feet (Young and Eyre 1937, Langner 1953). Thus two or three seed trees per acre would seem inadequate for effective pollination. Quality will be maintained only if the best trees are able to disseminate; if reseeding is left to suppressed trees and wolf trees, as often happens, a serious racial impoverishment might result locally.

The cones open best on the warmer days of autumn when there is little wind to spread the seeds (Conzet 1913). Thus, though the winged seeds are capable of travelling some distance, up to 900 feet (Woolsey and Chapman 1914), they ordinarily come to rest within a radius comparable to the height of the seed tree.

Germination Conditions

Normally white and red pine seeds germinate in the spring or early summer when the most important environmental factors, temperature, moisture and oxygen, are favourable. Occasionally there is some pregermination in the fall (Eliason 1938).

TEMPERATURE

Ideal temperatures for germination are between 68°F. and 86°F. (Anon. 1948). It is poor below 60°F. (Roth and Riker 1943). There are bound to be

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favourable temperature conditions at some time during every growing season, but they are often associated with drought. Extreme desiccation associated with high surface temperatures on some seedbeds can reduce germination and kill white pine seedlings (Smith 1951). Insolated polytrichum moss and moist mineral soil are less subject to lethal temperatures than other seedbeds.

MOISTURE

Any soil wetter than the permanent wilting point will provide enough water for germination of white and red pine seeds, providing other conditions are favourable. At the Petawawa Forest Experiment Station red pine seed lying on the surface of coarse sand was found to germinate only when watered daily and partially shaded (Fraser and Farrar 1955), but on fine sand good germination took place without either shading or watering. The drying effects of wind and sun are unfavourable to germination except when the seed is on a medium such as rotten wood, which supplies moisture. A high water table will provide an adequate supply of water even on coarser materials (Stoeckeler 1950). Evaporation is also reduced by shading, which therefore favours good germination. On the other hand a tree canopy may, through transpiration and interception of rainfall, induce drought in the natural seedbed and thus deter germination. It can also retard the initial growth of white pine seedlings in the spring, but not significantly (Smith 1940).

AERATION

Germinating seeds also need oxygen. If the seed is in soil much wetter than field capacity, aeration may be inadequate, and germination may fail because of lack of oxygen and accumulation of carbon dioxide.

DORMANCY

Even when temperature, moisture and aeration are favourable, many seeds may not germinate because of dormancy caused by an impermeable seed coat or by internal conditions in the seed (Evanari 1949). Red pine seed is not subject to embryo dormancy but white pine seed is. A remedy is stratification—moist storage for 30 days at 50°F., or for 60 days at 40°F. (Anon. 1948). Natural stratification occurs on the forest floor in the autumn and early spring, causing most seeds to germinate later in the spring. Some seed may remain viable while stored in the duff, particularly if conditions for germination are poor. Under dry, sealed storage, pine seed will keep up to 5 years at ordinary temperatures and up to 10 years at 32° to 41°F. (Anon. 1948).

NATURAL EFFECTS

Red and white pine may germinate but will not grow under dense shrubbery, on thick litter or sod, or in the heavy ashes of recent burns (Conzet 1913, Smith 1940, Cheyney 1942, Smith 1951). Best germination conditions consist of partial shade, light vegetation and litter, with some mineral soil exposed (Shirley 1933, Smith 1940, Smith 1951). In the natural pine forest these conditions usually evolve after fire or local disturbances such as windfall or erosion (Nichols 1935, Maissurow 1935, Spurr 1953).

Seedling Development

The factors influencing germination apply likewise to early survival and growth of the seedlings, although perhaps in different degrees.

SEED WEIGHT AS A FACTOR

An important factor is weight of the seed. Heavier seed not only germinates earlier, but also survives better than light seed of the same lot (Spurr 1944). Moreover, it produces heavier seedlings in both species for at least the first 3 years, the effect diminishing with age (Spurr 1944, Hough 1952, Pauley *et al.* 1955.) Heavier seedlings, in turn, grow better in height for at least the first 10 years than do lighter seedlings (Hough 1952).

COMPETITION

Competition takes on added importance as the cotyledonous seedling develops—competition for light, moisture and space.

Red pine is less tolerant of shade than white pine. It requires about 35 per cent of full sunlight for the satisfactory establishment of seedlings (Grasovsky 1929, Shirley 1932), whereas white pine can manage with 20 per cent (Smith 1940) or 25 per cent (Atkins 1957). The establishment of red pine is considered uncertain in light values below 17 per cent and impossible (past the cotyledonous stage) in less than 5 per cent of light (Bates and Roeser 1928, Shirley 1932). White pine, however, can survive in less than 7 per cent full light, although this level is too low for good growth (Smith 1940). Once past the ground cover, the abundance of red pine seedlings increases with light up to full sunlight, and the height growth also increases up to 63 per cent of full daylight (Shirley 1932, Mitchell and Rosendahl 1939). Controlled experiments with white pine seedlings (Logan 1959) show that height growth increases with increasing light up to 55 per cent of full sunlight, and diameter growth increases up to full light.

A dense overstorey or layer of shrubs suppresses and greatly weakens pine seedlings (Smith 1951). Also the leaf fall from a deciduous canopy often smothers cotyledonous seedlings. Later, in the sapling stage, pines growing in mixed stands may be subject to whipping and consequent leader deformity from adjacent hardwood saplings.

GROWTH RATES

The growth rate of pine in the wild forest is slow, particularly in shade. They reach only an inch or two in height the first year. After 4 or 5 years height growth begins to increase appreciably and after breast height is attained (at 8 to 10 years) it generally averages from 1 to 1.5 feet per year. In the best conditions, however, the young pines may grow up to 4 feet in height and one inch in diameter per year (Harlow and Harrar 1941).

DAMAGING AGENTS

There are many outside factors hindering early survival and growth. The various insects and diseases involved are described later. Rudolf (1948) lists numerous other agents such as those considered below.

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Weather

Among the weather effects, summer droughts and unusually high temperatures (above 130°F.) may kill needles and buds and sometimes whole pine seedlings (Shirley 1936). Unseasonal frosts can also be lethal or injurious to seedlings growing in susceptible locations (Fraser 1953, Kienholz 1933). Unusually severe winter weather may cause some mortality or at least defoliation. Retardation in growth, as well as deformity or death may result from any of these effects.

Wildlife

Wildlife plays its part also. The cotyledonous seedlings are subject to destruction by rodents and birds, and by trampling of larger animals. As well as the smaller rodents, rabbits (*Lepus americanus*) can cause appreciable damage during their population peaks (Krefting and Stoeckeler 1953, Marshall *et al.* 1955, Anon. 1936). The white-tailed deer (*Odocoileus virginianus*) is also involved. Despite the fact that pine is classed as starvation food for the deer, seedlings may be heavily browsed in overpopulated areas and during severe winters (Clepper 1931, Swift 1948). White pine appears to be more susceptible to browsing than red, but much less susceptible than jack pine (Horton 1959). The worst animal damage on red pine is caused by porcupines, which eat the stem bark, often girdling the upper crown (Stiell 1955).

Thus the hazards are many, but once at the sapling stage most have been left behind.

Vegetative Reproduction

Red pine does not reproduce vegetatively in nature; white pine is capable of layering (Lutz 1939), but insignificantly so. Both species can, of course, be reproduced artificially through grafting and cuttings, but again red pine is less receptive.

CUTTINGS

Only with great difficulty can stem cuttings of red pine be rooted without treatment (Rudolf 1957). However, special chemical treatment will allow leaf bundles of young seedlings to root well (Jeckalejs 1956).

The ease with which white pine can be propagated through cuttings depends on the origin of the material. Considering cuttings from one-year-old wood, rooting ability decreases with tree age (Delisle 1954). Reasonable success can be obtained, but not from older trees (Doran *et al.* 1940, Deuber 1942, Doran 1946, Thomas and Riker 1950). Farrar and Grace (1942) obtained 60 per cent success with cuttings collected from lower branches of 10 to 15 year old trees in August; they found that the month of collection was important. Different clones vary distinctly in rooting ability, and some clones vary widely from year to year. Material which originated as rooted cuttings proved superior to cuttings of seedling origin for 9 years (Patton and Riker 1958). However, successive generations of rooted cuttings from the same origin will decrease in rooting ability markedly with each repetition (Delisle 1954).

GRAFTING

Grafting is more expensive than cuttings in propagation but is more conducive to success. It greatly facilitates breeding; flower-bearing scions from mature trees can be grafted onto convenient root stocks of the same or related species. Thus eastern white pine is often grafted onto other 5-needled pines. Red pine can be successfully grafted to Scots pine (Holst 1956), and to Mugho pine (Ahlgren 1954), but rarely to jack pine (Rudolf 1957).

Grafting is best done in the spring, after root elongation starts in the case of white pine, and later, after the commencement of shoot elongation, in red. Fall grafting is possible, but the results are usually poorer. Red pine scions can be kept dormant overwinter in a deep freeze (0°F.) and be successfully grafted in the spring. Bagging the grafts for a while increases success (Holst 1956). Vigorous nursery-grown root stocks are preferable to naturally regenerated seedlings.

Rooting Habits

Studies on the rooting of red and white pine are few and largely confined to seedling and sapling stages, understandably enough. Lutz (1937) dealt with the subject of white pine rooting in relation to certain soil properties. Day (1941), Adams and Chapman (1941), and Garin (1942) covered various aspects of red pine rooting. But a comprehensive picture of root form development and specific variability on a representative range of sites was lacking until Brown and Lacate (1959) undertook a comparative study on mature red and white pines growing on diversified sites at Chalk River, Ontario. The succeeding illustrations (Figures 12, 13 and 14) and points stem largely from their findings, with some generalizations involving the results of the previous investigations as well.

ROOT FORM DEVELOPMENT

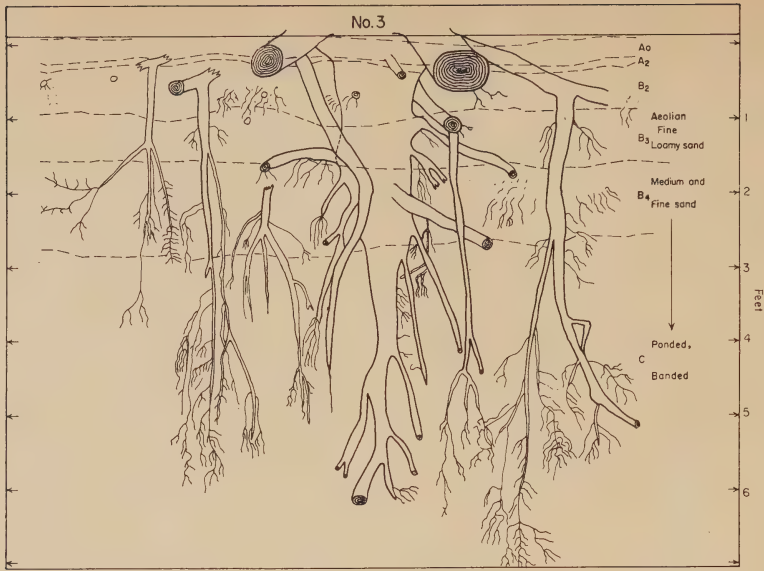
During the first few years young pines of both species usually develop a tap root and numerous branched laterals. Red pine tends to maintain its tap root more than white pine although this is largely influenced by soil conditions. Also, rooting of red pine tends to be more restricted in area. For practical purposes, however, the rooting habits of both species are fairly similar on most sites. Both are capable of penetrating deeply into the subsoil, and of developing numerous central and lateral sinkers in favourable conditions.

Older parts of the root increase in diameter by annual layers of wood laid down by the cambium. However, the annual layer of the root is much more irregular than that of the stem. In lateral roots of pines the upper part of the ring is much thicker than the sides or lower part, so that the root becomes oval in cross-section, with the original centre nearer the lower side.

LATERAL ROOTING

The lateral roots of both species are generally large and only a few inches below the ground surface in the relatively rich A and B horizons. Usually, smaller vertical roots or sinkers descend from these main root branches. If unhindered by competition from neighbouring trees, the longest laterals may extend beyond the limits of the crown to a distance roughly comparable with the height of the tree. White pine seems to be more extensive in lateral rooting than red; the longest white pine lateral recorded by Brown and Lacate (1959) was 60 feet from the stump, whereas the longest red pine lateral was 40 feet. Fine roots develop along the length of the main laterals in both species. These are usually concentrated within the top foot of soil.

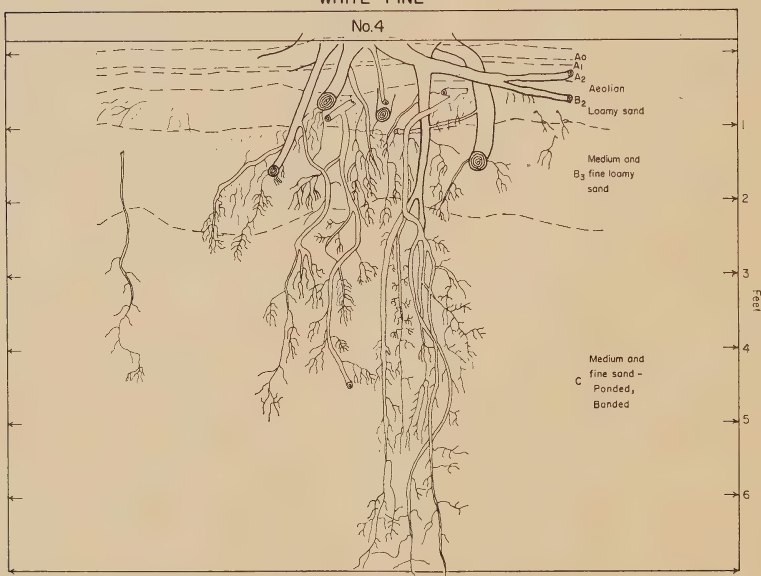
RED PINE



- Strong tap-root and numerous sinkers descend to 12 feet.
- Fine root fans frequent through B and C horizons.
- Laterals in B extend to 35 feet.

Site I Age — 72
Height — 74

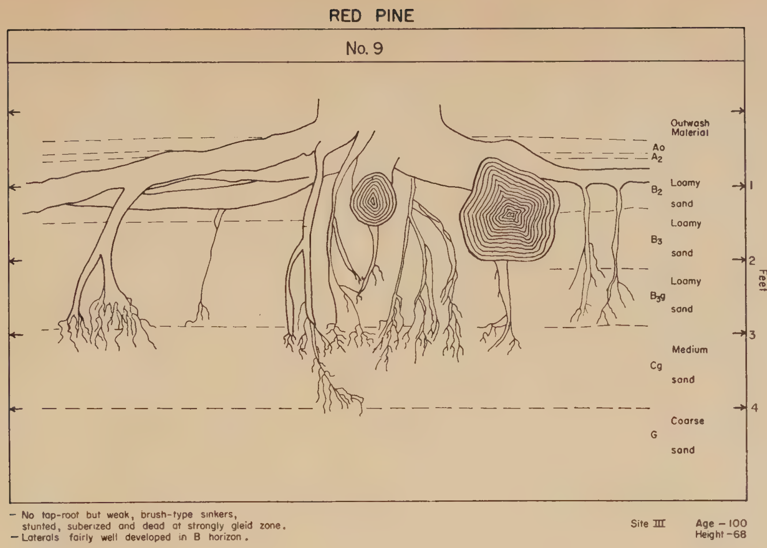
WHITE PINE



- No definite tap-root, but numerous strong central sinkers descending to 10 feet.
- Fine root fans abundant through B and C horizons.
- Laterals in B extend to 35 feet.

Site I Age — 64
Height — 72

Figure 12. Comparative rooting of red and white pine in somewhat dry coarse-to-medium soils.



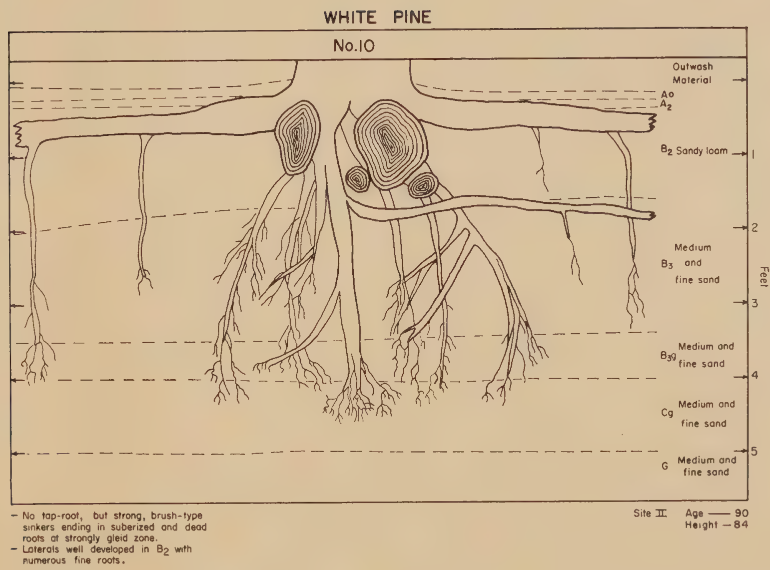
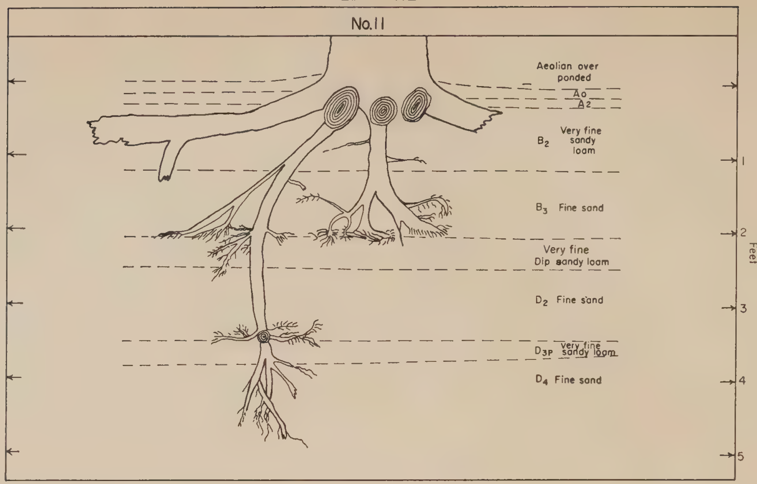


Figure 13. Comparative rooting of red and white pine in moist, coarse soils.

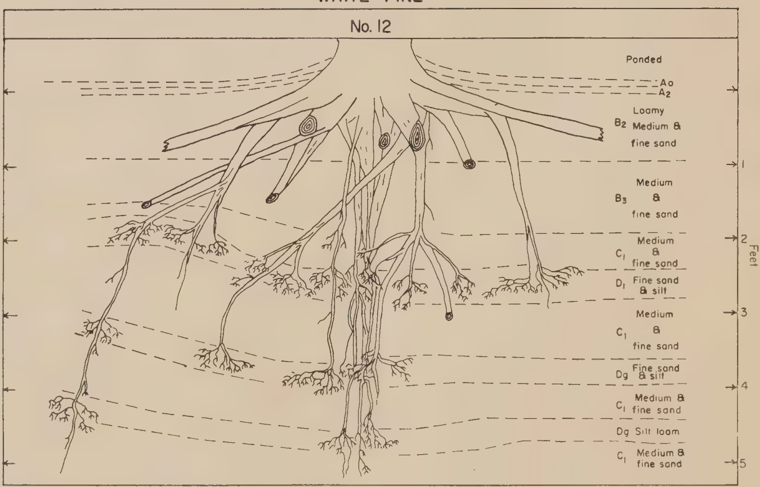
RED PINE



- No distinct tap-root.
- Central and lateral sinkers sparse, develop progressively.
- Masses of fine roots in each fine stratum.
- Laterals extend in B to 30 feet.

Site I Age —— 70
Height —— 75

WHITE PINE



- No distinct tap-root.
- Moderate number of central and lateral sinkers develop progressively.
- Masses of fine roots in each fine stratum.
- Laterals extend in B to 30 feet.

Site I Age —— 70
Height — 77

Figure 14. Rooting tendencies of red and white pine in interbanded, medium-textured soils of fresh moisture regime.

VERTICAL ROOTING

Both central and lateral sinkers occur in each species but are particularly strong and abundant in white pine, presumably supplanting a taproot. In both species the vertical roots may penetrate as deep as 5 to 15 feet, the actual depth varying with the soil characteristics; it is probable that they may extend even deeper in soils which are particularly loose and well drained.

Generally the taproot and central sinkers of the red pine tend to go through materials which can be penetrated only with difficulty, rather than be diverted; the reverse is true for white pine, whose roots spread out over the surface of the obstruction. Thus in shallow soil over bedrock the red pine roots will penetrate the crevices and be restricted laterally whereas the white pine will spread out and reach other pockets of deeper soil. This difference may explain the superior growth of white pine on certain shallow soils with deep pockets. It may also explain the greater persistence, in a stunted form, of red pine on knolls of deeply fractured bedrock.

On sites with a high water table the root systems of white pine consist almost entirely of lateral branches which form a shallow plate-like root system. This illustrates the wide adaptability of white pine rooting to variation in site conditions. Perhaps the absence of red pine from such wet sites is a result of its lesser adaptability.

PRODUCTIVITY EFFECTS

Soil Conditions

Good stem growth depends, among other things, on a healthy root system. Moist soils with a high zone of gleization are not conducive to healthy rooting in either species, as witnessed by the frequency of suberized and dead root tips in glei horizons and at the upper surface of hardpan formations, and also as reported by Stone, Morrow and Welch (1954) in New York. Again, however, white pine is more adaptable than red, extending its roots deeper into the poorly aerated gleid zones (note Figure 13).

Sandy soils with thin strata of moderately fine material at a depth of two to four feet are highly productive, favouring the development of stratified masses of fine roots just above and sometimes below the finer-textured soil layers (note Figure 14). Loose-structured fine sandy soils, as found in dunes, can also be highly productive in terms of height growth when drainage is not excessive, as in the cases of Figure 12. Such conditions permit the development of exceptionally vigorous, extensive root systems with sinkers penetrating deeply into the subsoil. Generally speaking, the loamier and fresher the soil, the better the rooting.

Productivity decreases wherever root restriction occurs, where a hardpan or gleid stratum approaches the surface, and where dry, very coarse, compacted materials are present. The latter prevent easy penetration and cause a bent, stunted root system.

Mycorrhizae[3]

Mycorrhizae are another factor in rooting and productivity. A symbiotic relationship develops between the tree through its short roots and the mycorrhizal

[3]This information on mycorrhiza was supplied by Dr. V. Slankis, Forest Biology Division, Canada Dept. of Agriculture, Southern Experiment Station, Maple, Ontario.

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fungi through their hyphae which coat and penetrate these roots and extend into the soil. They absorb nutrients from the soil and transfer them to the tree (Melin and Nilsson 1950, 1952, 1953). Also, the fungus supplies its own metabolic by-products to the root cells, inducing morphological and other changes (Slankis 1955, 1958). The benefit of these effects is best manifested by the fact that for successful afforestation with conifers in certain treeless regions, it has been necessary to inoculate the soil with mycorrhiza-forming fungi. A good example is provided by an experiment with white pine seedlings planted in prairie soil (Hatch 1936).

OTHER PRACTICAL IMPLICATIONS

An important practical effect of rooting habit is windfirmness. Both pines exhibit a natural deep-rooting tendency on normal soils devoid of inhibiting strata of any sort, and thus can be considered relatively windfirm.

Functional root grafts involving different trees can occur at the seedling stage (Kuntz and Riker 1955). This can also be frequent in maturing white pine stands, both natural and planted (Bormann and Graham 1959). This may have an important bearing on stand vigour through the translocation of nutrients on the one hand, and diseases on the other.

Growth Characteristics

PHENOLOGY

Seasonal Stem Growth

Normally, white and red pine produce one flush of growth each year, white pine commencing a little later than red pine. The cambium and adjacent tissues take in water and swell in late winter, but it is believed that actual cell division may occur first in the buds. In any case cambial cell division starts just below the buds and proceeds downward (Fraser 1952), continuing as radial growth for a period of up to four months, unless halted by drought. Most of the growth takes place in a much shorter period, particularly in denser stands and other conditions. Seasonal trends in radial growth of pines growing under different conditions are shown in Figure 15.

Stem elongation or height growth begins some time in May and extends for 6 to 18 weeks according to records for various years at diverse localities (Rudolf 1957). Growth is rapid at first, then diminishes; 90 per cent of it may occur in the first half of the period. At the peak of the growth period, 60 per cent of elongation takes place at night, and best growth occurs on cool nights (Kienholz 1934). The initiation of shoot growth seems related to temperature and hence varies widely from year to year in one stand, and from stand to stand according to local climate. The amount of radial growth appears closely related to precipitation, particularly early in the growing season (Dils and Day 1952), whereas the amount of shoot elongation seems to be influenced by the precipitation of the previous growing season (Motley 1949). Height development of red pine takes place in two stages, during two growing seasons (Duff and Nolan 1953). The first stage occurs as the bud is formed in the latter part of the growing season. This bud determines the general size of the new shoot and the number of needle bundles on it, which are related to the growing conditions of the same year. In the spring of the following year the new shoot develops more or less independently of the weather conditions at the time. However, if these conditions are markedly more favourable than they were when the bud was formed, the new

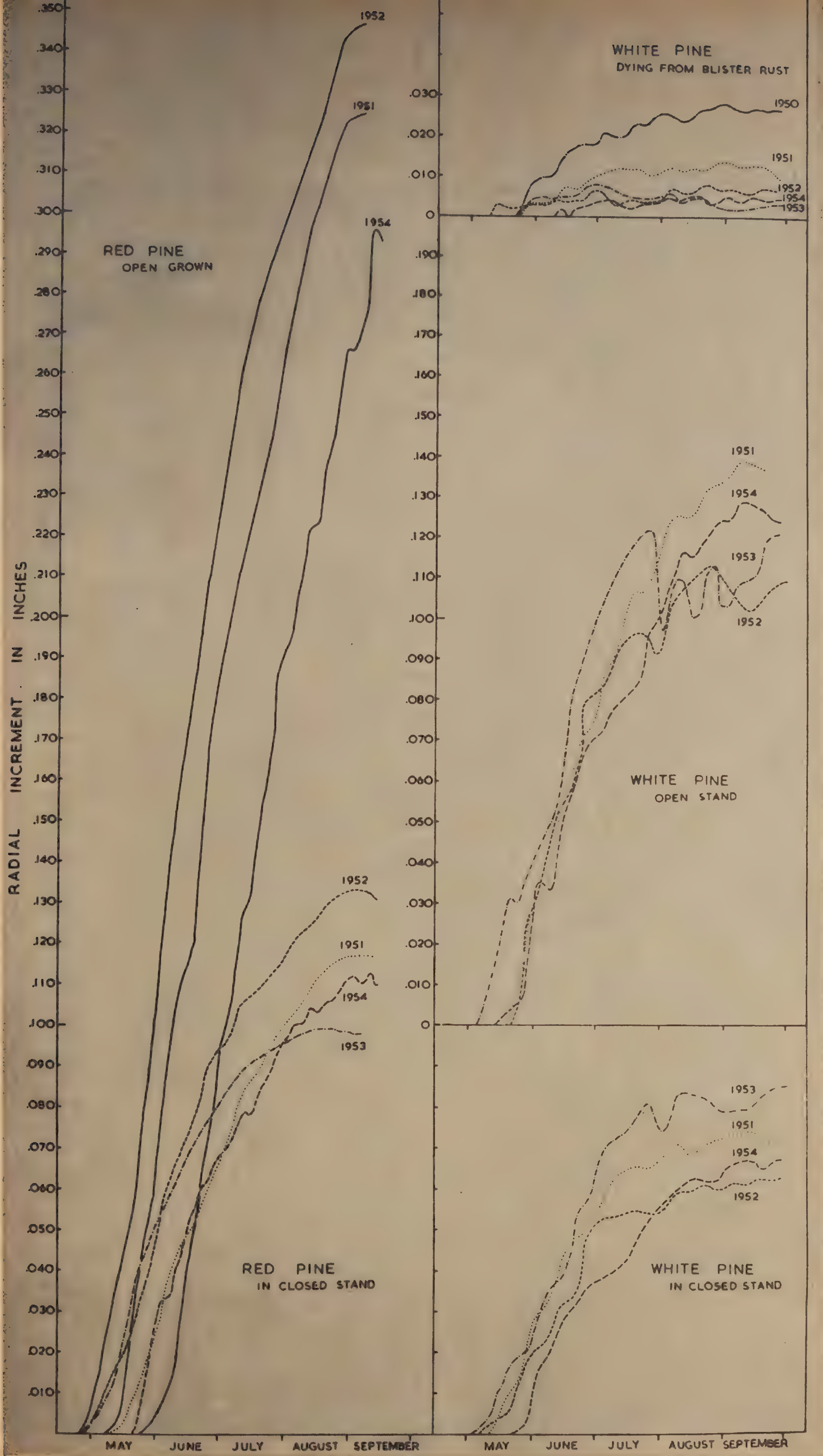


Figure 15. Radial growth in red and white pine as followed through four growing seasons at the Petawawa Forest Experiment Station. (Graphs prepared by D. A. Fraser.)

shoot may grow longer than normal; conversely a severe spring drought can reduce its growth. Hence, height growth will sometimes be correlated to the weather of the year in which it occurs, but more often to that of the preceding year.

Branch Growth

Studies by Friesner (1943) and Friesner and Jones (1952) demonstrate the relationships between branch and stem growth in the pines. Elongation begins at about the same time in all axes of the tree. It is greater in any particular year in the main stem than in the secondary branches, and greater in the secondary than in the tertiary branches. Growth in the secondaries decreases successively on branches from the top whorl downward.

Abnormalities

Bud formation generally occurs before growth ceases, in August in northern Michigan (Rudolf 1957). Previous development of the lateral buds in the terminal cluster may cause "summer" or "lammas" shoots in both pine species, which can result in forking if one or more of the laterals gains dominance over the terminal shoot (Büsgen and Münch 1929, Carvell 1956, McCabe and Labisky 1959). It is postulated that late summer rains followed by a dry spell may cause this phenomenon. Forking can result from other effects as well—through heredity, and from damage to the terminal bud or leader.

Foliage Development

Pine needles flush a few days after shoot elongation begins (Rudolf 1957). Seedlings in nurseries usually leaf out earlier than those in the forest presumably in response to higher temperatures in the open. Age of the mother tree appears to influence the time of flushing in young seedlings; it is earliest in the progeny of mature trees and latest in that of immature and older trees (Rudolf 1954). At Petawawa, Ontario, new needles on red pine start to develop in late May and continue at least until mid-September (Stiell 1959C). White pine needle growth has been reported to begin in May and continue to mid-August (Brown 1915).

Root Growth

Root elongation starts earlier and continues later than growth of other tissues. In white pine it often temporarily slows or ceases entirely during midsummer, perhaps because of soil drought. However, it can be maintained all winter in greenhouse conditions, suggesting that temperature is effective (Stevens 1931). It is also possible that root elongation is a cyclic process (Baker 1950). It is suspected that radial growth in the roots commences a little later, and continues somewhat longer, than in the trunk.

HEIGHT DEVELOPMENT

General Patterns

In a fairly constant environment, height growth of the pines follows a common pattern—it begins slowly, increases rapidly to a maximum, then tapers off in decadence. The tendencies for both species are illustrated in Figures 38 to 41 (stem analysis trends). The major difference between the two species in

individual height growth trends appears at maturity (100 years or more), when white pine continues to grow relatively well, while red pine slows to a standstill, at 140 years (Eyre and Zehngraff 1948).

Effects of Site

It is apparent that site and history strongly influence the rate and amount of height growth. Dominant trees of each species in natural stand conditions attain maximum growth at about 30 years on the best site and about 50 years on the poorest (Figures 38 and 39). In plantation conditions, however, red pine reaches the maximum growth point before 20 years (Figure 40). Bull (1931) found the point to be 12 years on good sites and 22 on poor in Connecticut plantations, and this range is corroborated in Duff and Nolan (1953), applying to lightly stocked conditions.

Effects of Stand Density

The pattern of height growth is modified by various factors, the most significant of which is probably competition or stand density. It is not clear what the relationship is between spacing and height growth. There have been numerous spacing studies made, mostly in pine plantations, but many of the results conflict (Ralston 1954, Schantz-Hansen 1952, Stiell 1958) (see also "Thinning", page 77, and "Stand Growth and Yield", page 104.)

Natural stands of red pine are usually understocked (Rudolf 1957) but can range to extreme overstocking, at which growth stagnation occurs (Eyre and Zehngraff 1947). It generally holds that very high stand density levels will greatly reduce tree height growth, and very low levels will slightly reduce it (Spurr 1952, Hawley and Smith 1954). There is evidence that open spacing does result in diminished average height of red pine saplings (Shirley 1942). In this case the tallest trees were associated with dense thickets suggesting a possible ecological advantage in that type of distribution.

Dominant vs. Average Height

The relative significance of dominant height and average height is a major facet in this problem. In dense stands of red pine dominance is well expressed by 10 to 15 years of age, whereas in more lightly stocked stands it usually takes 20 to 30 years (Conzet 1913). Also involved here is the matter of temporary suppression and response to release, dealt with on pages 35 and 74. Dominant height, because of its independence of density over a wide range, provides a useful index of site quality.

DIAMETER GROWTH

Internal Patterns

The thickness of the annual layer of wood varies from tip to stump according to a pattern, as worked out in detail for red pine by Duff and Nolan (1953). Starting at the top of the tree, the width of the annual layer increases for several internodes, reaches a maximum, decreases gradually toward the stump, and then increases again to ground level. The maximum thickness is reached between the second and eleventh internode. The longer the crown the further down is the point of maximum thickness. At any internode the thickness is related to the

amount of brightly illuminated foliage feeding that internode. The amount of foliage per whorl increases for a number of whorls down from the tip, but the effective illumination is already decreasing, owing to shading from the upper leaves, before the amount of foliage reaches a maximum. The whorl where the maximum amount of food is synthesized by the foliage thus occurs only a short distance down from the tip. Another reason for the progressively thinner annual layer toward the base of the bole is the increasing amount of branchwood that must be formed, and the increasing size of the bole.

That the food synthesized by the leaves in a particular whorl of branches is used mainly by the cambium below that whorl is illustrated by de-budded red pine which have a few whorls of branches at the base and a long branchless trunk above (Bickerstaff 1945). The cambium on the branchless part of the bole is supplied with food mainly by the needles on it; they are limited, hence the trunk is spindly. Below the uppermost whorl of branches the trunk is much larger, in keeping with the more abundant food supply provided by the needles on the branches. Further evidence of the downward translocation of food is provided by the abnormally swollen trunk above a girdle (removed ring of bark) contrasted with the lack of diameter growth below the girdle.

This theory (Duff and Nolan 1953) that the thickness of the annual sheath at any place on the bole is related to its proximity to the food supply above explains why diameter growth at breast height is greater in trees with living branches well down the trunk—the larger the crown, the greater the diameter growth at breast height. In extremely small-crowned trees the annual ring may even be absent at breast height. Near the top of the tree, diameter growth is relatively unaffected by the amount of crown on the lower parts (Bickerstaff 1946).

The thickening of the annual layer in the butt region of the tree is related to mechanical stresses rather than nearness of the food supply. A convenient equation to determine the relationship of stump diameter to breast-height diameter has been devised by Hampf (1954) for white pine.

Foliage growth is completed in one growing season, but the needles remain on the tree for two to four years and continue to synthesize food. On debudded trees they persist on the trunk for one year longer (Bickerstaff 1945). Needles fall off mostly in the autumn, after turning brown.

External Effects

External factors affecting diameter growth—site and stand density—are dealt with under thinning and pruning (pages 77, 85), and later on a stand growth basis (page 109). Suffice it to say here that direct relationships apply—the wider the spacing and the better the site, the greater the stem diameter of the pines (Smithers 1954, Allison 1954, Stiell 1959, etc.)

Longevity

The oldest red pine recorded is 307 years of age but it is suspected that the species may live to about 400 years (Rudolf 1957). White pine is even longer-lived. Trees over 450 years old have been reported (Harlow and Harrar 1941), and a maximum age of over 500 years has been suggested (Nichols 1935). The most appropriate rotation age for forest management is discussed under "Stand Growth and Yield" (page 104). It generally ranges between 80 and 140 years depending on commercial requirements and conditions.

COMPARATIVE AUTECOLOGY

The bulk of the following sections is taken from a report by Horton and Brown (1960) on the ecology of the two pines, as individual species and as a forest type, in the Great Lakes–St. Lawrence Forest Region. This is supported in some cases with other relevant references.

Local Climate

The broad effects of climate in controlling the ranges of white and red pine have been touched upon previously. Red pine, it appears, is somewhat better adapted to rigorous conditions. Specific preferences in *local* climate are more difficult to assess because of a wide amplitude of tolerance in both pines, and because local climatic effects are usually obscured by other factors of site and stand history. Again, however, red pine seems more capable of withstanding extremes than white pine, as suggested by its predominance on the driest sand plains which are exceptionally hot in the daytime and cold at night. It is well recognized that white pine reproduction depends on some degree of protection for germination and survival (Smith 1951, etc.), more so than red pine. At the same time there can be too much protection; observations in mixed pine stands of Eastern Ontario suggest that natural white pine reproduction is more abundant where, through exposure to wind and sun, evaporation is high.

A major local climatic effect is frost damage, to which both pines are susceptible on low-lying sites where cold air collects, or on dry sand flats where night radiation promotes rapid cooling. Frost damage is greatest when the foliage first flushes in the spring, but cotyledonous seedlings may be affected throughout the growing season or in the fall. It is symptomized by dead growing tips which result in deformity or, in extreme cases, death of seedlings. In red pine plantations these effects of frost frequently appear in patches with scattered resistant specimens remaining unharmed. The fail spots in these cases are usually characterized by a "frost pocket" vegetation type composed of *Comptonia*, stunted *Vaccinium* spp., sedges and grasses.

Other weather effects of local silvicultural significance are windfall, sunscald and winter injury. Both pines are relatively windfirm on most soils, at least in Eastern Ontario, but there are locations which are particularly susceptible—mainly sites where rooting is restricted (Brown and Lacate 1959). A study of hurricane damage in central New England (Curtis 1939) showed that white pine is more wind-resistant than red pine for the first 25 years. Damage is greatest in dense, old, evenaged stands and on exposed southerly slopes. Sunscald and winter injury may be related. They both cause death of tree tissues on the southwest side of the trunks of trees facing openings. In one case of its occurrence in white pine, the trees most subject to damage were in the intermediate crown class (Huberman 1943). The cause was attributed to the trunks warming up in the afternoon sun in winter, then rapidly freezing at night.

Light

Both pines are classed as intermediate species in various relative shade-tolerance scales which have been devised, but white pine is definitely more tolerant than red (Kramer and Decker 1944, Baker 1949, Graham 1954). On average upland sites in Ontario the pines and more commonly associated tree species have been arranged in decreasing order of tolerance as follows: balsam fir,

sugar maple, beech, hemlock, white spruce, yellow birch, white pine, black spruce, white birch, red oak, red maple, red pine, jack pine, trembling aspen, largetooth aspen, and pin cherry (Horton and Brown 1960).

Under a dense canopy of mixed pines, white pine reproduction may on some sites develop and persist, but red pine rarely becomes established and even more seldom persists. The hardier white pine seedlings can survive in a stunted form for up to 40 years under moderate to heavy shade, retaining a fair supply of needles. Upon release they require two to three years to develop a normal unrestricted growth rate. Red pine seedlings which have germinated under dense shade usually die the first or second year, rarely persisting to ten years. The persistent specimens have sparse foliage and, if released, take a few years longer than white pine to recover.

Red pine requires a minimum of about 35 per cent of full sunlight for satisfactory seedling establishment (Grasovsky 1929, Shirley 1932), whereas white pine requires only 20 or 25 per cent (Smith 1940, Atkins 1957). As to height growth in seedlings, that of red pine increases with light up to 63 per cent of full sunlight (Shirley 1932, Mitchell and Rosendahl 1939) while in white pine it increases only up to 55 per cent of sunlight (Logan 1959).

White pine remains more tolerant at later ages. In fact, Rudolf (1959) suggests that red pine loses some measure of tolerance after the seedling stage. In mixed pine stands the red pine grows faster for at least the first 40 years and often beyond 100 years (Smithers 1954, McCormack 1956), after which the white pine gradually achieves dominance, finally outliving the red.

Soil Moisture

White pine is capable of growing on a wider range of soil moisture conditions than red pine. It is found from wet swamps to arid sand plains and rocky ridge tops. Red pine is generally more restricted at the moist end of the scale but is well adapted to extremely dry sites.

Superior growth rate in both species ordinarily occurs on fresh to moist, well-drained sites, although exceptionally favourable nutrient supply and soil structure can maintain excellent growth on somewhat dry sites, especially those suited to deep and extensive rooting. On the driest and wettest conditions growth of both species is, quite naturally, retarded. Excepting these extremes, and other variables being equal, there is a general direct relationship between soil moisture and pine height and diameter growth—the greater the available moisture, the better the growth (Husch and Lyford 1956, McCormack 1956).

On the wet sites white pine is often confined to raised humps, but it can grow on peaty soil with a high water table, probably depending on periodic lowering of the water level. Red pine, when it occurs at all on the moister conditions, is usually inferior to white pine in growth, but it can develop moderately well when the ground water is aerated.

On the driest sites red pine is often superior to white. This may be because red pine roots tend to penetrate deeper into very coarse sands and utilize the crevices in rock more readily than those of white pine (Brown and Lacate 1959), thus taking advantage of deep moisture.

Soil Texture and Structure

If other factors, particularly soil structure and species competition are constant, there is a correlation between occurrence of the pines and soil texture.

Generally red pine is more abundant on the coarser sandy soils, and white pine on the finer sands or loams. Wilde (1946) considers 5 to 10 per cent of silt and clay as suitable for red pine, and 15 to 25 per cent for white pine, but he cautions against the use of this relationship in soils having strata of various textures. The following composite field samples illustrate differences in specific textural preferences typical of Ontario conditions (Horton and Brown 1960):

	Horizon	Sand (%)	Silt (%)	Clay (%)
Soils on which red pine is abundant	B_2	68	28	4
	B_3	80	18	2
	B_C	95+	3	0
Soils on which white pine is abundant	B_2	55	40	5
	B_3	63	34	3
	C	72	25	3

A relatively high proportion of sand is characteristic of the soils most inhabited by both species. Thus they are more likely to be found on glacio-fluvial or aeolian materials than on tills or lacustrine soils.

Variations in reproduction capacity and growth rates of both pines have frequently been attributed to textural differences. Lutz and Cline (1947) and others have reported poorer white pine reproduction on heavier as compared with light sandy soils. Growth, on the other hand, can be greater on finer textured sandy soils with a higher silt and clay content, as Scott and Duncan (1958) have shown with height growth in red pine plantations. It is apparent that such relationships may not be directly attributable to soil texture. The finer materials are generally superior in water-holding capacity and nutrients, which could account for the superior growth; they also promote the development of competing vegetation which discourages pine reproduction.

The effects of soil structure are usually masked by those of other factors but do become evident under some circumstances. On compacted soils, root penetration is difficult for both species. White pine is generally more abundant than red pine on such conditions but there is little difference in respective growth rates. On soils with "hardpans" and heavy lacustrine soils, red pine is somewhat more stunted, a situation that may be caused directly by the adverse structure, or indirectly through its effect in deteriorating vertical drainage.

The best conditions of texture and structure for outstanding pine growth are generally those that balance available moisture with good aeration. These may be found in interbanded soils of medium sand and finer materials where moderately shallow rooting occurs, or in loose, medium and fine sand mixtures of aeolian origin which permit exceptionally deep and extensive rooting.

Soil Nutrients

Both pines ordinarily occur and grow satisfactorily on soils of moderate to low fertility. A sample analysis of a typical waterlaid sand or sandy till of granite origin, in the central Ontario portion of the Great Lakes-St. Lawrence Region, is as follows (Horton and Brown 1960):

Horizons	pH	P	K	Ca	Mg
			(parts per million)		
A_0	4.4	10	90	100	7
B_2	5.1	—	60	145	4
B_3	5.5	—	50	115	—
C	5.5	—	40	175	2

As emphasized elsewhere, the more tolerant species, particularly hardwoods, generally crowd out the pines on richer soils.

In the matter of soil pH, Wilde (1946) suggests that white pine has a wider tolerance in both directions, recommending a pH range of 4.7 to 7.0 for it as compared with 5.0 to 6.5 for red pine. Observations in natural Canadian stands indicate that both species are capable of performing well on soils tending to acidity but white pine is more tolerant of basic conditions. Satisfactory growth in either species may be found in moderately acid soils with a surface pH as low as 4.0, whereas on somewhat basic soils with a surface pH of 7.0 to 7.5, white pine can thrive but red pine may be inhibited.

White pine does not appear to be appreciably retarded in growth by lime concentrations near the soil surface; red pine does. However, a limy C horizon is not a serious drawback to red pine when overlaid by moderately acid A and B horizons.

A strong concentration of iron and humus in the upper B horizon appears to be adverse for both pines. Inferior white pines growing on such conditions are sometimes locally called "yellow pine". The characteristic chlorosis and poor vigour which results may be related to low nitrogen or potassium contents or to poor drainage which is often associated.

Evidence of nutrient deficiency affecting pine is sparse. Lafond (1954) reports a case of magnesium and potassium deficiency in certain plantations in Quebec where growth was restricted. Stunted, deformed and chlorotic red pine plantations may be found in overworked old-field sites which are high in lime or low in magnesium and potassium, and also on natural low-nutrient outwash sands in which quartz is the principal component (Horton and Brown 1960). The quickest remedy in such cases is artificial fertilizing (White 1956, etc.). Over a longer term the soil may be reconditioned by certain vegetation. As an example, it has been demonstrated that white birch helps restore potash-deficient forest soils, making the nutrients available to white pine and thus improving growth (Walker 1953).

In contrast to the above there are certain localities or landtypes with exceptionally fertile soils which result in excellent pine growth on sites which are mediocre in other respects. An example is the aeolian sand of the Chalk River area of eastern Ontario, which is made rich and productive for pine by an abundant feldspar and mica component.

Podzolization under Pine

The occurrence of both pines is closely associated with moderate podzolization. Pine litter, on decomposition, promotes an acid leaching process which usually produces minimal or normal (orterde) podzols on dry and fresh materials,

and is associated with humic podzols, gleyed podzols and gleysols on moist to wet materials. The degree of podzolization is modified by the associated species, the nature of the parent soil material, the drainage, and the climate. Of the coniferous associates, hemlock, fir, and the spruces, especially black spruce, encourage the process. The hardwoods, especially sugar maple and beech, and to a lesser extent the birches, tend to weaken it and encourage the formation of brown soils, such as the brown podzolics and brown forests. Basic parent materials discourage podzolization, partly because they favour the hardwoods.

SYNECOLOGY

Pine Distribution Factors

Natural pine distribution is the result of a great complex of site and stand history factors which in every locality vary in relative importance and interact upon each other. These variations and interactions make it very difficult to choose the primary causative factors in the local distribution of pine, but it is possible to detect some general relationships.

GEOGRAPHY AND CLIMATE

On a subregional scale the relative abundance of pine in the forest is affected by the interplay of geography, physiography and climate. The general tendencies in the pine region of Ontario and Quebec have been summarized by Horton and Brown (1960) with reference to Halliday's revised forest sections (Rowe 1959). (See Figure 16 and Table 4.)

Various sections and parts of sections considered representative of the sequential climate scale of the region are shown in Table 4 together with the relative distributions of pine and the most stable species therein. The basis for determining the sectional climates is partly local experience and partly the mean annual weather records (Anon. 1947). Though the differences in the weather data are not wide, they are consistent and indicate with some objectivity relative variations within the region.

Table 4.—Broad Distributional Relationships of Pine

General Climate	Forest Section	Pine Distribution	Stable Species
36[1] Cold-moist. 35[2]	Northern L. 4b	Scattered on dry sites	Spruces, fir, birches
38 Cool-moist 34	Southern L. 4b	Frequent on dry sites	Tolerant hardwoods
37 Cold-dry 28	L. 9, Western L. 11	Abundant on dry-moist sites	Pine, spruce, fir
39 Cool-dry 30	L. 4e, Eastern L. 10	Abundant on dry sites	Pine on dry, exposed sites Tol. hwds. on fresh loams
40 Warm-dry 29	L. 4c	"	"
41 Warm-moist 34	L. 4d	Restricted to dry sites	Tolerant hardwoods

[1]Annual Mean Temperature
[2]Annual Mean Total Precipitation

FOREST REGIONS OF EASTERN CANADA
(Halliday Revised)
Acadian A
Boreal B
Deciduous D
Great Lakes-St. Lawrence L
Regional Boundary
Sectional Boundary
Range of White Pine
Range of Red Pine
ONTARIO
QUEBEC
U S A
JAMES BAY
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
Lake St. Clair
Lake Nipigon
ST. LAWRENCE RIVER
Kenora
QUEBEC
MONTREAL
OTTAWA
North Bay
Mississagi River
Coulonge River
Chalk River
Gatineau
L. Kipawa
L. Timagami
L. Nipissing
RED PINE
WHITE PINE
L12
L11
L10
L9
L8
L7
L4a
L4b
L4c
L4d
L4e
L3
L2
L1
D1
B
50°
45°
90°
85°
80°
75°
70°
65°

Generalizing, it is apparent that the pines prefer dry conditions. Stands are abundant and relatively stable only in the climatically drier sections, and in moister sections the pine species are largely restricted to dry sites by strong competition from tolerant hardwoods or, to the north, boreal mixedwoods.

PHYSIOGRAPHIC SITE

Relationships of pine and associated species on a spectrum of physiographic sites in a particular section are shown in Figure 17 (Horton and Brown 1960). Details of the classification method are dealt with later. Again a tendency on the part of the pines to prevail on the drier conditions is evident, this time on a local site level. The dryness may be due to exposure, excessive topographic drainage, coarse soils, or any combination of these. Thus pines predominate on the shallow upper slopes and ridge tops and on the water-worked and wind-blown materials, and as the physiographic site becomes more mesic, pine distribution generally wanes.

FIRE

The pines are primarily fire species in that their silvical characteristics are adapted to conditions best effected by forest fires. Climate and local site may not be directly responsible for natural pine distribution, but indirectly through fire history. Fire will in the long run be more common in the drier conditions; so, therefore, will pine. Moreover, once established, the pine vegetation itself through its high combustibility will increase the probability of fire. Thus on dry areas a cycle develops and pine prevails, varying in local density according to seed availability. In contrast, the moister conditions tend to encourage fire-resistant vegetation, tolerant hardwood trees and dense deciduous shrubbery, which become stabilized, excluding pine.

Another factor in fire history is the existence of areas with an abnormally high frequency of dry electrical storms, which greatly increase fire frequency. Three such areas are around the Mississagi, Chalk and Coulonge Rivers, each of which features extensive pineries today.

Fire is not necessarily beneficial in promoting the distribution of red and white pine. It may, if it is repeated at a short enough interval, or if it follows a clearcutting, destroy all advance growth and seed trees in a locality. In such cases the less desirable pioneer species, jack pine, aspen, or white birch, will replace red and white pine. This, unfortunately, has happened over a large proportion of the pine region, particularly in those sections less suited climatically and physiographically to the prevalence of pine. As Maissurow (1935) put it, the decline of white pine in eastern Canada was not caused by either fire or logging directly, but by disturbance of the general balance between the seed-bearing capacity of the forest and the effectiveness of fires—namely, the elimination of seed sources, the over-frequency of fires in some areas, and the lack of fire in others.

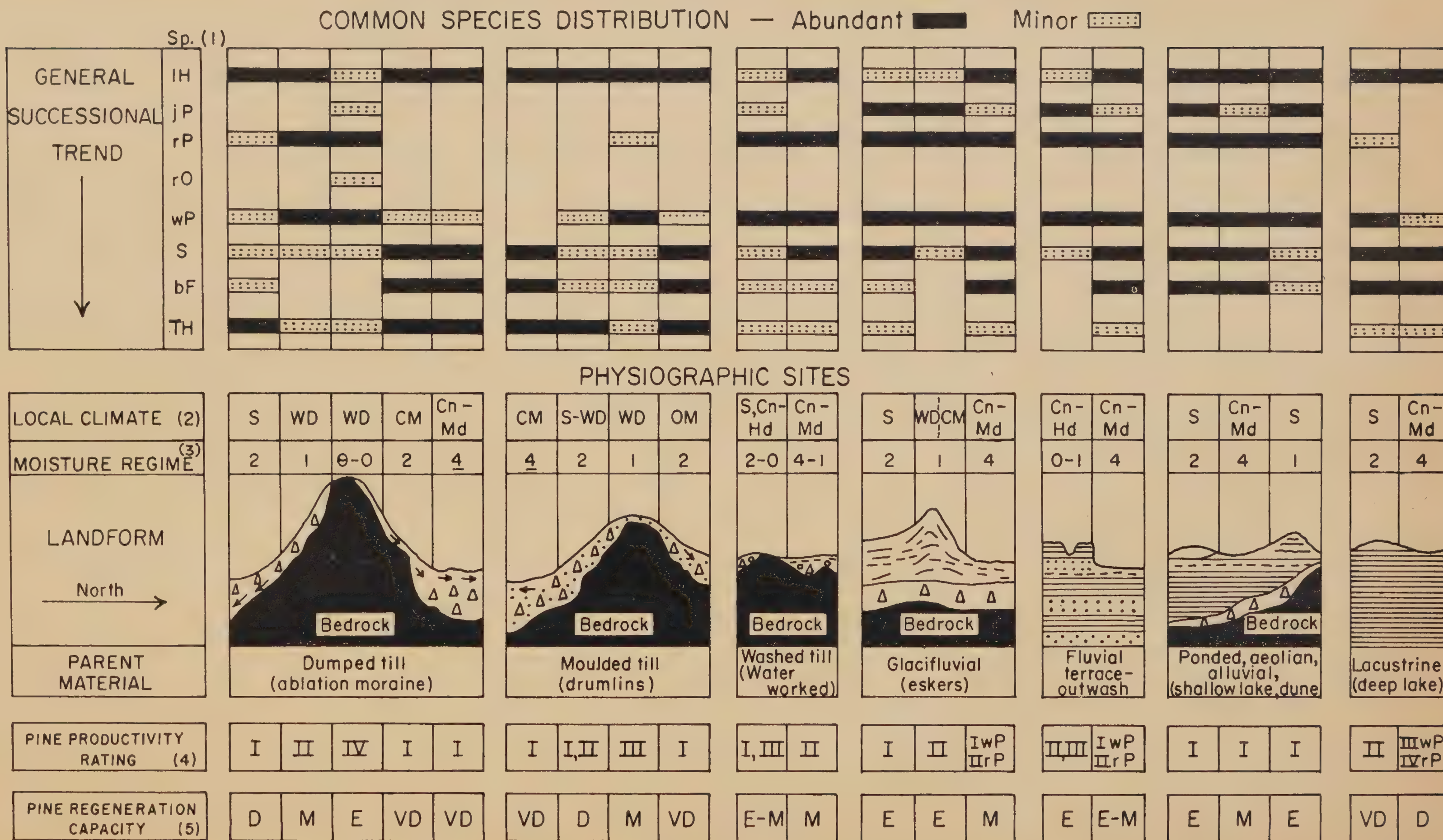
CUTTING

Cutting, apart from fire, has influenced pine distribution in various ways. Obviously it has decimated the old-growth stands. Intensive operations have in some localities eliminated pine by destroying advance growth and seed source. Diameter-limit cutting, practiced on pine for many years, ensured some seed supply and reproduction in most areas but it could seldom be called adequate

FOREST ASSOCIATIONS IN RELATION TO PHYSIOGRAPHIC SITE

IN THE MIDDLE OTTAWA SECTION

SHOWING PINE PRODUCTIVITY AND REGENERATION CAPACITY



(1) Species symbols–See appendix (2) S=Standard WD= Warm-dry CM = Cool-moist Cn-Md = Cool night, Mod. day Cn-Hd = Cool night, Hot day
(3) Θ = Very dry O = Dry 1 = Somewhat dry 2 = Fresh 4 = Moist (underlined-if seepage) (4) I = Good II = Mod. III = Poor IV = Very poor

either in quantity or quality. Competing trees and shrubs of both pioneer and tolerant classes, usually undesirable hardwoods, have been generally encouraged to the detriment of the pine. Satisfactory stands of white pine (rarely with red pine) have developed after cutting only when there was the coincidence of an abundant, ripe seed crop and a receptive seedbed, or when a crop of suppressed seedlings was released. These circumstances probably occurred infrequently in former years but are becoming more common as pine management intensifies.

OTHER EFFECTS

There are other natural processes which can bring about pine reproduction in quantity, but they too involve disturbance of the stand and site. Windthrow is one—periodic hurricanes are said to be responsible for extensive original white pine stands in parts of the northeastern States (Goodlett 1954). The pine became established on upturned mineral soil. Erosion or other soil disturbances may also create favourable regenerating conditions (Maissurow 1935).

A large proportion of white pine stands existing during the latter 19th and early 20th centuries in New England and New York developed on abandoned fields of low agricultural value. Many such stands have reverted to hardwoods through clearcutting, unless the cutting coincided with a pine seed crop to produce regeneration, and the hardwood competition was controlled by man or grazing animals (Lutz and Cline 1947, Foster and Kirkland 1949).

Once pine reproduction has become established, there are a variety of external factors that can alter the normal course of stand history. White pine particularly is susceptible to damage—browsing and weevilling which reduce growth and ruin form, and blister rust which kills trees of all sizes. Red pine is relatively free of these drawbacks and thus, along with other competing species, gains an advantage over white pine in mixed stands.

Pine Associations and Successional Relationships

The foregoing deals with the main bases of establishment of pine. It is evident that each of the factors affects competing species in similar or dissimilar ways. The result of all these effects is the mosaic of forest cover types. These cover types are dynamic; various species interactions result in continuous forest successions which are quite different for each type. Horton and Brown (1960) recognize four broad pine cover types in the Great Lakes–St. Lawrence Forest and describe their successional trends as follows:

PINE—TOLERANT HARDWOOD COVER TYPE

The tolerant hardwoods prevail on the deeper, moulded or dumped tills. Red pine cannot compete under these conditions but white pine may be temporarily abundant on disturbed areas—severe burns or old fields. Once established, white pine may persist because of its longevity and superior height growth but reproduction has little chance except occasionally on rocky ridge tops or other dry locations. Elsewhere as a rule a dense understorey of hard maple and other tolerant hardwoods develops at an early stage and eventually dominates, precluding pine reproduction. Hard maple is the prevalent species; minor components, usually local, may be beech, yellow birch, red oak, basswood, and hemlock.

PINE—INTOLERANT HARDWOOD COVER TYPE

This type is frequent over a wide range of sites. It originates after fire or cutting or both. The intolerant hardwoods, aspens and white birch, which dominate at first, become decadent early (50 to 70 years) on the drier sandy plains but continue to suppress the pines longer on till materials. Once they deteriorate, a rank shrub layer consisting mainly of *Corylus cornuta*, *Acer spicatum*, *Viburnum* and *Rubus* spp. develops. The previously suppressed pines will dominate the canopy for a time but their reproduction will be sparse. Balsam fir and spruce usually become established among the shrubs and may remain dormant for many years until the canopy thins. White birch may maintain a minor position by regenerating in temporary openings. On the till sites where a local seed source is available, tolerant hardwoods may invade the type.

PINE—SOFTWOOD COVER TYPE

This is relatively restricted in the south, becoming commoner to the north where it occurs on a broad range of sites. The softwoods other than pine are predominantly balsam fir, and white and black spruce. Successional development is obviously toward the spruce-fir except on upper slopes and dry sand plains where white pine may reproduce and persist. On dry, limy sites in the south, where white cedar and white spruce are significant associated species, the development is probably to cedar, with some white pine persisting in openings, especially on limestone plains.

PINE COVER TYPE

Pine is relatively stable as a type only on drier conditions where pure stands have developed. On valley water-worked sites, stands of fire origin containing the three pines—white, red and jack—can be found. In the course of succession the jack pine will fall behind first, then the red pine, leaving the white dominant. Sporadic red and jack pine reproduction may occur in openings but white pine will generally reproduce in abundance, and fir and spruce usually intrude. Pine types on moister, richer sites are temporary and develop rapidly to spruce-fir-birch or to tolerant hardwoods, depending on which is locally prevalent.

Site Classification

Various methods of classifying pine sites have been applied, some purely for descriptive purposes, others for different sorts of appraisal. The several familiar approaches used are considered separately below, and a co-ordinated classification is presented.

PHYSIOGRAPHIC SITE

The local site potential in forest production depends primarily on the physical features of the soil and climate which in combination may be called physiographic site. The relationships of pine and associated species on a spectrum of physiographic sites in a section of Ontario have been worked out in some detail by Horton and Brown (1960) as shown in Figure 17. The site criteria stressed are soil moisture regime and local climate within distinct landforms, following Hills (1952, 1954, 1959). Landform is recognized by Hills, Logan and Brown (1956), Scott (1958) and others as a primary site variable indicative of soil

Table 5.—Summary of Heimburger's Type Classification for the Petawawa Forest Experiment Station

Type	Vegetation	Stand
Vaccinium-Comptonia	Vaccinium, Comptonia, Epigaea, Hypnum schreberi, Pteridium.	Jack Pine, Red Pine.
Maianthemum-Corylus	Vaccinium, Maianthemum, Corylus, Oryzopsis, Gaultheria, Pteridium.	Red Pine, Jack Pine, White Pine.
Aster-Corylus	Aster, Corylus, Aralia, Maianthemum, Oryzopsis, Trientalis, Pteridium.	White Pine, Red Pine, mixed Aspen, Birch and Balsam Fir (White Spruce)
Trillium	Hard Maple seedlings, Lonicera, Medeola, Smilacina, Trillium, Streptopus, Polygonatum.	Tolerant hardwoods, old-field softwoods, Aspen.
Vaccinium	Vaccinium, Carex pennsylvanica, Oryzopsis, Maianthemum, Aralia.	Jack Pine, White Pine, Red Pine, Red Oak.
Aster-Gaultheria	Aster, Maianthemum, Gaultheria, Oryzopsis, Aralia, Pteridium.	Red Oak, White Pine, Aspen.
Cornus-Maianthemum	Cornus, Maianthemum, Rubus triflorus, Vaccinium, Pteridium.	Balsam Fir, White Spruce, White Birch, Red Pine, Red Maple.
Cornus-Linnaea	Cornus, Trientalis, Clintonia, Aralia, Medeola, Linnaea, Streptopus, Pyrola, Acer spicatum.	White Birch, White Spruce, Aspen, Balsam Fir, Red Maple Black Ash.
Aralia	Aster, Cornus, Aralia, Trientalis, Maianthemum, Clintonia, Medeola, Mitchella, Acer spicatum, Pteridium.	Aspen, White Birch, White Pine, White Sruce, Basswood, Black Ash.

texture, structure and nutrient characteristics combined. Moisture regime and local climate are rated in arbitrary scales as shown below the figure. Both depend largely on topographic position; moisture regime also reflects soil porosity. A simplified application of this technique is shown in Table 6, and details of the site rating methods are given subsequently.

SITE INDEX

Site index curves, indicating site quality through dominant height at a standard age, have been presented for one or both pine species in several publications (Frothingham 1914, Gevorkiantz and Zon 1930, Barrett 1934, Spurr 1952, Ardenne 1950, Husch 1954, McCormack 1956). These represent a variety of regions, physiographic conditions and stand histories, so that comparisons and generalizations are of little value. A means of using the site index of red maple for estimating that of white pine when suitable pine trees are not available has been worked out recently in New England (Foster 1959). Applications of site index are presented under "Productivity Rating" (page 59).

Table 6.—Broad Site Types of Pine in the Middle Ottawa and Similar Sections

Pine Site Type	Type Division	Major Pine Species	Important Associates	Vegetation(1) Type	Topography	Parent Soil(2) Material	General Ratings(3) Regeneration	General Ratings(3) Productivity
Pine Ridge	Southern(4)	wP,rP	rO,tA, etc.	Aster-Gaultheria	Dry granite ridge	d/b or w/b	E	IV–III
	Northern	jP, wP	bS	Vaccinium	Dry granite ridge	d/b or w/b		
Pine Plain	Xerophytic	rP	jP	Vaccinium-Comptonia	Dry terrace or plain	u,a+d/b,w/b	M–E	III–II
	Mesophytic	wP,rP	jP,A,wP	Maianthemum-Corylus	Somewhat dry plain	u,a,p+d or w		
Pine Upland	Mixedwood	wP,rP	A,wB, bF,wS	Aster-Corylus	Somewhat dry to moist slope	d,m+w,r	D	II–I
	Softwood	wP	bF,S,wB	Cornus-Maianthemum	Moist lower slope, pocket or bench	u,w+a,p		
Hardwood Pine Upland	Mesophytic	wP	hM,Be,yB eH	Trillium	Somewhat dry to moist drumlin slopes, etc.	Rich d,m	V D	II–I

(1) Heimburger's Petawawa types which most closely correspond with the chosen site types.
(2) Landform classes (minor representatives follow the + sign).
b = bedrock, d = dumped till, w = washed till, m = moulded till, u = uniformly stratified outwash and terrace.
r = roughly stratified eskers and kames, a = aeolian, p = ponded materials.
(3) Ratings are listed in Figure 17, and described in text
(4) Geographic Division; even within a forest section there is a general trend from deciduous to coniferous species progressing north.
(5) wP = white pine, rP = red pine, jP = jack pine, rO = red oak, tA = trembling aspen, bS = black spruce, A = aspen, wB = white birch, bF = balsam fir, wS = white spruce, S = spruce, hM = hard maple, Be = beech, yB = yellow birch, eH = eastern hemlock

SUBORDINATE VEGETATION TYPES

In the pine region the vegetational associations are particularly complex because the region is essentially transitional between northern coniferous and temperate deciduous conditions, and also because most pine stands in their present form have been irregularly disturbed by cutting. Thus it is difficult to classify vegetation types characteristic of pine communities. No comprehensive phytosociological classification exists for the whole pine region but there are several local descriptions for various pine areas in the U.S.A. and Canada. These include: Ilvessalo 1929, Anon. 1930, Wilde 1932, Heimburger 1936 (published in Sisam 1938), Vezina 1956, and Baldwin 1958.

For the sake of description, Heimburger's (1936) work at the Petawawa Forest Experiment Station, unpublished itself but described in Sisam (1938), is perhaps most relevant since it deals fairly comprehensively with a major pine area situated in the heart of the region under consideration. The types involving pine are presented in Table 5 with summaries of significant species, and the ecological positions of some types are indicated in Table 6.

FOREST-SITE TYPES

Figure 17 represents an attempt at detailed co-ordination of the above classification methods in a given forest section. Pine distribution and growth are shown in relation to the important physiographic sites and associated species. A fairly large number of sites and species are involved, presenting a complex pattern. For most applications in forest management a broader grouping of conditions is satisfactory. To this end Horton and Brown (1960), relying on previous work by Logan and Brown (1956), have described four "forest-site types", which are generalized combinations of forest cover type with broad physiographic site or landtype. These four site types have been named according to their characteristic cover and topographic occurrence, and three of them are further divided according to particular differences in site and species composition. They are shown in Table 6 along with their normal physiographic ranges, important tree associates, and characteristic lesser vegetation type (of Heimburger 1936).

PRODUCTIVITY RATING

An evaluation of relative productivity is the commonest aim of site classification. Productivity can be thought of in two senses, that of the existing stand and that of the site potential. Both involve physical site quality; the former also reflects the haphazards of stand history. Hills and Pierpoint (1959) outline a method for taking both into account using "ecological units" (comparable to forest site types) each of which is assessed for pine productivity on the bases of present stocking, yield quality (from local measurements), degree of hardwood competition, and cost required to maintain pine through silviculture.

In relating existing pine stands to site, it has been noticed that productivity, or growth of individual trees within the stand, appears to be influenced directly by soil moisture regime. Husch and Lyford (1956) also found this in white pine stands in New England. The relationship in Ontario is shown in Table 7 using as a measure of productivity McCormack's (1956) figures of average site index, or relative dominant height at 50 years grouped in four arbitrarily defined classes.

Table 7.—Site Index and Productivity Rating for Pine

Productivity Rating	Average Site Index		General Moisture Conditions
	wP	rP	
I	61	61	fresh and moist
II	50	51	somewhat dry
III	43	44	dry
IV	34	36	1. very dry 2. wet

Other site factors may be indicative of quality—for instance, Young (1954) found in Maine that the site index of white pine decreases as the depth of the A horizon and the percentage of stones in the B horizon increases—however, moisture regime is perhaps the most workable criterion.

This general relationship between pine productivity and soil moisture can be altered by special conditions. Exceptionally high productivity may result in some localities from unusually rich parent material originating from feldspars, micas, basic volcanic and sedimentary materials, and from particularly favourable rooting conditions. Subnormal productivity may occur where the soil nutrient balance is amiss, where rooting is restricted by bedrock, compacted soil or stagnant ground water, and where exposure is excessive.

REGENERATION CAPACITY RATING

Pine regeneration depends first on the abundance and vigour of the competing lesser vegetation and tree species. This in turn is controlled chiefly by the physiographic site and the stand history. Chance seeding and vegetative regeneration play some part, but in most cases this too is partially affected by the main factors through their control over species distribution in the preceding stand and in adjacent stands. Though the abundance of the competing species is readily discernible, the vigour may be temporarily suppressed by a dense main overstorey; it is the potential vigour that is important.

Four ratings of regeneration capacity have been described by Logan and Brown (1956). Their respective positions on the various physiographic sites are shown in Figure 17.

Group E—Sites where regeneration is easy, in sparse heath, heath-grass, and heath-herb types of lesser vegetation. The sites supporting these types usually have very dry and poor soil, and severe local climate (either warm-dry with desiccating winds, or cold-by-night and hot-by-day).

Group M—Sites where regeneration is moderately easy, in dense heath or weak shrub-herb and herb types. The sites included here are generally characterized by somewhat dry and poor soil, and moderately severe local climate (warm-dry southerly slopes with weakly desiccating winds).

Group D—Sites where regeneration is difficult, in moderate shrub-herb and herb types. The sites in this group usually have fresh, rich soil, and standard local climate.

Group VD—Sites where regeneration is very difficult, in shrub-herb, shrub, and herb types with a strong development toward dense shrubs or hardwoods. The sites in this group are usually characterized by moist, rich soils, and cool-moist local climates.

Exceptions to these general trends are not infrequent. Conditions which especially favour pine regeneration are the coincidence of a good seed supply with a fire which reduces competition and prepares a receptive seedbed, or with cutting in a well-stocked stand where ground competition is undeveloped. Subnormal reproduction levels may result from a continued seed crop failure or from an exceptionally dense overstorey of trees, shrubs or advance-growth fir or hardwoods. Summarizing, all features which discourage competition encourage pine reproduction and vice versa.

Figure 18. White pine on a fresh, moulded till site; productivity = I; reproduction prevented by vigorous shrubs and maple advance growth.

Figure 19. A mixed pine-aspen type on somewhat dry dumped till; productivity = II; pine reproduction discouraged by dense shrub-herb vegetation.

Figure 20. A red and white pine type on a dry, sandy, outwash plain; productivity = III; white pine seedlings frequent amid the heath vegetation.

Figure 21. A poor stand of red pine, white pine, red oak, and aspen on a rocky ridge of dumped till; productivity = IV; scattered pine reproduction.

ARTIFICIAL REPRODUCTION

Introduction

The contents of this section represent for the most part a direct synopsis of a recent publication by Stiell (1959A) which reviews the subject at large but with particular reference to Ontario practices.

Hundreds of millions of red and white pine trees have been planted in eastern Canada and the adjoining states in the last half-century. Ontario alone plans to produce almost 10 million seedlings of each species for planting in 1960, and production figures are much higher than this in the Lake States and New York State especially.

Both species have proven widely adaptable to a variety of conditions and particularly useful for the reforestation of abandoned and marginal farmlands. At first white pine was the favoured plantation species because of its greater value in lumber, but its susceptibility to damage by blister rust and weevil later ruined its reputation, and red pine became more popular. Then a serious damaging agent of red pine was introduced to the continent—the European pine shoot moth—somewhat upsetting the prospects for pure red pine plantations. Now, with the development of techniques which control or limit the agents damaging white pine, this species is regaining a large measure of popularity. Mixed plantations of the two pines and perhaps other species hold more promise today.

Seed Handling

PRODUCTION

Seed production characteristics of the two pines are discussed in detail under "Silvics" (page 29).

Red pine cones ripen in September or October, turning purple with reddish-brown scale tips. Their specific gravity when ripe is 0.80 to 0.94 (Anon. 1948); thus they will float in kerosene (Anon. 1941) or SAE 20 oil (Eliason and Hill 1954). Collection should take place within 30 days of ripening or much of the seed will have dispersed.

White pine cones ripen in late August or September when their colour is yellow-green with brown-tipped scales, and their specific gravity 0.92 to 0.97 so that they will float in linseed oil. The cones should be collected within 20 days, since seed dispersal is usually completed by October (Anon. 1948).

It may be feasible to induce cone production artificially. A limited trial with mature red pine in Nova Scotia, which involved incomplete girdling, i.e., the removal of two half-circles of bark and cambium from opposite sides of the stem, six inches apart and overlapping slightly, resulted in a significant increase in average cone production per tree (Drinkwater 1958).

COLLECTION

It is important to preserve inherent high quality in plantation stock through careful selection of seed crop trees. Superior qualities to look for in red pine include a straight stem, good natural pruning, moderate crown width, reasonably thin, horizontal branches, and resistance to the European pine shoot moth, Saratoga spittlebug and red-headed pine sawfly. Those of white pine are a straight stem, slender leader, moderate self-pruning and crown width, nearly horizontal branching, and resistance to blister rust and weevil (Rudolf 1956).

Unless provenance tests have indicated that particular geographic sources produce superior strains, it is advisable to plant in any area only stock of local seed origin. In the Ontario pine region, seven seed zones are recognized on the basis of effective temperature and moisture, delineated to conform with convenient geographic boundaries. Seed from different zones is kept separate so that planting stock can be labelled as to zonal provenance and transplanted accordingly (Stiell 1959A).

Cones must be collected manually. Normal yields of cones from mature trees in Ontario are about 1.5 bushels for red pine and 5 bushels for white (Stiell 1959A). Data relating cone and seed production per acre according to condition are provided in Table 3, page 30. If cones are to be stored temporarily between collection and shipment they must first be air-dried to prevent overheating and moulding.

EXTRACTION

Collected pine cones are first air-dried for three or more weeks, reducing the moisture content from 40 to 25 per cent, and hardening the otherwise troublesome resin. Then, to complete the process of cone opening, kiln-drying is usually carried out. The conditions required for extraction vary with the species and the type of kiln as Table 8 shows.

Table 8.—Schedules of cone drying for different types of kilns

Kiln Type	Time (hrs.)		Temp. (° F.)		R.H. (%)	
	rP	wP	rP	wP	rP	wP
Hot air	48	24	140[1]	120	under 35	do
Infra red lamps	4		170[1]			
Convection	24–72		130–140	110–120		
Forced draft	5	8	170	140	21	40
Forced hot air	9	12	130	120	15	37
Internal-fan extractory	7	4–5	150	140	18	41

[1]Cones water-soaked during process. The above data are taken from Stiell (1959A), Anon (1948), and Stoeckeler and Jones (1957).

CLEANING AND STORAGE

After extraction the seeds and cones are separated by screening. Then the seeds are dewinged by machine, after which the cleaned seed is dried to 5 to 6 per cent moisture content for storage (Stiell 1959A).

Red pine seeds stored in sealed containers will retain their viability for 3 to 5 years at ordinary temperatures, and more than 10 years at 32 to 50°F. (Anon. 1948). One lot of seed stored for 19 years gave 94 per cent germination (Eliason 1949). Sealed white pine seed will stay viable for 8 or more years at 32 to 41°F. (Anon. 1948).

GERMINATION

Red pine seed normally germinates without pre-treatment, but white pine is subject to embryo dormancy which, to be broken, requires stratifying for 30 days at 50°F. in moist acid peat or sand (Anon. 1948), or at 37°F. on wet filter paper under glass (Stiell 1959A).

Standard germination tests indicate that red pine generally has a somewhat higher germinative capacity than white. According to practice in Ontario, red pine should germinate at 75°F. in 8 to 9 days by the Jacobsen test, and in 15 days by the sand test, giving more than 90 per cent germination by both methods compared with 75 to 80 per cent for white pine (Stiell 1959A). Test results from elsewhere show similar but slightly lower specific percentages (Heit and Eliason 1940, Stoeckeler and Jones 1957).

NURSERY PRACTICE

Procedures for raising red and white pine stock vary somewhat from region to region and between different nurseries. Stiell (1959A) describes in detail the standard practices in Ontario provincial nurseries and summarizes those in New York as reported by Eliason (1949) and in the Lake States (Stoeckeler and Jones 1957). The succeeding description of recommended practices combines all three sources.

SEEDBED CONDITIONS

Nursery seedbeds for the two pines should be on well-drained, non-alkaline, sandy soil, artificially fertilized with manure and chemicals. The following fertility standards have been found satisfactory in the Lake States:—

	Red Pine	White Pine
Reaction (pH)	5.4	5.4
Base exchange capacity (milliequivalents per 100 gm. soil)	8.0	10.0
Total nitrogen (per cent)	0.12	0.14
Available nitrogen (pounds per acre)	30	35
Available phosphorus (P_2O_5) (pounds per acre)	50	80
Available potassium (K_2O) (pounds per acre)	150	200
Replaceable calcium (milliequivalents per 100 gm.soil)	3.0	5.0
Replaceable magnesium (milliequivalents per 100 gm. soil)	1.0	1.5

SOWING

The seed is sown by hand or drill, late enough in October or November to avoid fall germination. Fall sowing usually gives larger first or second year seedlings than spring sowing. The densities aimed at will vary with the age of stock required. In Ontario, where 2-2 stock is usually produced, normal densities are 75 to 160 seedlings per square foot. In the States the figure is 65 for stock that is to be transplanted, 50 for 2-0 stock, and 40 for 3-0 stock. For reference purposes, one pound of red pine seed, containing 52,000 viable seeds, produces about 11,000 seedlings.

CULTURE

Seed is covered with about 1/8-inch of sand and mulched with clean straw, pine needles or sphagnum moss. Germination ordinarily occurs about mid-May for both species, varying with the normal weather. Once it begins the protecting mulch is removed and replaced by lath screens providing half shade or more for white pine and less for red pine.

Surface irrigation is essential during the germination stage. Watering of red pine seedlings during the period from about 2 to 6 weeks after germination is avoided in Ontario, unless conditions are very dry, because it encourages damping-off, which constitutes a danger at this stage.

Damping-off, which involves chiefly the pathogens *Fusarium, Pithium* and *Rhizoctonia,* is encouraged by limy soils, and such conditions can be prevented to some extent by the application of thin layers of sterile silicaceous sand under and over the seed, following pelletting with a fungicide. Various chemical control measures are also applicable, the most common of which is treatment of the soil with $\frac{1}{8}$ fluid ounce of concentrated acid per pint of water (Stoeckeler and Jones 1957).

Once the succulent stage is past, the available soil moisture content in the top 8 inches should be 4 to 8 per cent for red pine and 5 to 10 per cent for white. One watering every 7 to 10 days is usually enough for transplants.

Weeding is generally done by hand for the first season. Chemical weed-killers are used but can be harmful to the seedlings; safe dosages of mineral spirits containing 10 to 12 per cent of aromatic hydrocarbons as found in the Lake States are:—

	Red Pine	White Pine
	(U.S. gal. per acre)	
4–6 weeks old	50	40
6 weeks to 1 year old	60	60
over 1 year old	75	75

Root pruning is not generally done although trials have shown that it can give denser, more compact and fibrous roots. (Stoeckeler and Jones, 1957).

Transplanting is the usual practice in Ontario where 2-2 stock is most popular. It is normally carried out in the spring using mechanical lifters and transplanting machines or manual methods and yale boards. The transplanted stock is not shaded but receives some watering and weeding by chemical weed-killers.

SHIPPING

The final lifting and shipping is normally done in the spring. The stock may be culled and graded or root-trimmed after lifting. It is bundled and packed in containers with wet sphagnum moss or comparable material. Packed stock awaiting shipment should be kept moist and may be stored without loss up to five weeks at temperatures from 34 to 40°F. and a high relative humidity. It is dangerous (Leech 1959) to store stock unrefrigerated for long periods, particularly towards the end of the growing season.

Planting

Most planting of red and white pine has been done on abandoned or marginal farmland. There is an increasing trend, however, toward reforesting cut-over and burned areas and low-grade hardwood and mixedwood stands with these valuable species. Much of the former planting was indiscriminate; now more attention is given to fitting the species to the site and history of the area. Thus red pine is generally favoured for the drier, open sites and white pine for the fresher, often partially-forested conditions.

SITE PREPARATION

Some site preparation is often necessary to facilitate planting or to reduce vegetative competition. A tree canopy of around 50 per cent may give valuable protection in the first season and increases survival (Anon. 1939, Rudolf 1950), but red pine will later become seriously suppressed under the direct competition. White pine is better adapted to underplanting, and the cover, if not too dense, can be useful in controlling weevil attacks. It may be necessary in view of these points to reduce the canopy by cutting, girdling or poisoning selected trees before or after underplanting.

81968-0—5½

If brush or scrub tree growth is present, its removal before planting may be advisable. A disc plough has been used successfully to do this job. Also effective is a pusher plough mounted in front of a tractor, which may pull a planting machine. (Rudolf 1950, 1953). One development to avoid is suckering of the bulldozed brush, particularly prevalent in aspen. The rapid initial growth of aspen suckers on all but the driest sites makes it unsuitable for underplanting red pine (Stiell 1959A).

On lightly covered but steep ground, furrows along the contours are very satisfactory in preparing the site. However, they should not be used on low-lying sites, heavier soils or blow sands, or in autumn planting on areas which may blow clear of snow. On very steep terrain, or where rocks, stumps or heavy cover preclude ploughing, hand-made scalps can be used in place of furrows (Anon. 1947, Grinnell 1953, Rudolf 1950).

PLANTING TIME

The period in early spring when the land can be worked yet plant processes are still dormant is preferable for planting. Fall planting can be successful under moist soil conditions, but the dangers are great—frost heaving on heavier, moister soils (Anon. 1947, Grinnell 1953), exposure and excessive transpiration on light soils (Rudolf 1950).

CLASS OF STOCK

Transplanted stock is traditionally used in Ontario. It gives better results in survival and initial growth, which often justify the expense of transplanting (Stiell 1959A). Also it is generally better suited for machine planting (Rudolf 1950). However, in the northern states 2-0 and 3-0 pine stock grown at lesser densities is standard for field planting, giving satisfactory results. In fact, root-pruned seedlings of both pine species have proven equal or superior to transplants (Foster and Kirkland 1949). Root pruning of 2-1 stock has given greatest success in survival but at an exorbitant cost compared with root pruning of 3-0 stock (Anon. 1942). The main point is that a well-balanced plant is required, one with a compact, fibrous root system and a moderate amount of foliage. The most economical technique which will produce it in any given nursery circumstances should be the object.

FIELD STORAGE

Stock may be stored in the shipping containers at the planting site for a short while, if it is kept shaded and moist. For longer periods it should be heeled-in. Circle-piling is often used for storing pine stock up to two weeks. In this technique bundles of seedlings are placed in a circle on the ground with the roots inwards and the diameter of the inner circle about one foot. Successive layers of seedlings are piled on, continually moving the roots closer until they touch at about three feet high. The roots of each layer are covered with damp moss and the pile is kept shaded. Thus the stock is neatly protected from both drying and physical injury. (Stiell 1959A).

Figure 22. A healthy plantation of red pine and spruce in an open hardwood stand.

PLANTING METHODS

Machine planting is the most efficient method where usable. Especially economical are the machines which can combine site preparation and planting in one operation. (Rudolf 1950, Grinnell 1953). Under reasonable conditions a machine may plant an average of 8,000 trees per day, and 4,000 to 5,000 is considered the economic minimum. Suitable conditions for machine planting include a fairly large and regular area, not overly steep or rocky, and reasonably clear of heavy brush and stumps. However, even these difficult obstacles are being overcome by the development of new, adaptable equipment. (Grinnell 1953).

Of the various hand-planting methods used in Ontario for pine, wedge-planting is generally recommended. In sod conditions the T-slit method may be more suitable, and where roots or stones make the other methods impracticable, hole planting is practiced. Ordinary slit-planting, though cheaper, gives poorer results, and should be used only with small stock on light soils. (Anon. 1947).

SPACING

Recommended spacings for plantations of red and white pine differ with site. The U.S. Forest Service suggests 6×8 feet on good sites and 6×6 feet on poor. (Rudolf 1950). In Ontario an average of 8×8 feet is recommended for red pine; this initial spacing permits thinning to be deferred until a salable product can be removed (Grinnell 1953).

Comparative spacing studies in red pine plantations have shown that average diameter and hence merchantable volume increase significantly with wider spacings, from 4×4 up to 10×10 feet (Byrnes and Bramble 1955, Baldwin 1958). From such a study at the Petawawa Forest Experiment Station it was found that red pine should be grown at 7×7 feet and could be commercially thinned in about 20 years. (Stiell and Bickerstaff 1959).

Closer spacing is advised on the poorer sites to allow for the expected greater mortality (Anon. 1947). If red pine are too close, however, (6×6 feet or less) such adverse effects as ice and snow damage, root resinosis, poor humus decomposition and hence decreased growth can result (Woodford 1949). White pine may be planted exceptionally close to limit weevil damage. At the Pack Forest spacings of 4×4 and 3×6 feet have given best results (Foster and Kirkland 1949), and at the Petawawa Forest Experimental Station a 2×2-foot plantation has produced sufficient undamaged stems to form a satisfactorily stocked stand (Stiell 1955).

COMPOSITION

Site is once again an important factor in view of its influence on stand development.

In mixed red and white pine plantations an alternate row arrangement of each species is commonly used. The drawback is that the white pine is initially suppressed by the red, up to 40 or 50 years in some cases (Heiberg 1953). Thinning is essential to bringing the white pine through, particularly on dry, light soils; thus the mixture is more likely to be successful on moist soils. An advantage in the arrangement is that the red pine develops greater diameters than in pure

Figure 23. Seventeen-year-old white pine, planted at 2 × 2 feet for weevil control.

stands. In Ontario a spacing of alternate rows 6 feet apart, with the white pine 6 and the red pine 8 feet apart in their respective rows, has been suggested. (Anon. 1947, Stiell 1959A).

Red and jack pine may also be planted in alternate rows, at 8×8 feet. The jack pine will outgrow the red on the drier sites but this can be remedied by thinning between 20 and 30 years (Stiell 1959 A & B). Similar mixtures of red pine with European larch and with red oak have shown success (Anon. 1947).

In mixtures involving white pine, alternate-row arrangements with larch, red oak, or on heavier soils white spruce, are possible (Anon. 1947). Underplanting of aspen stands combined with canopy regulation to balance weevil control with satisfactory growth of the white pine is a promising technique (Logan and Farrar 1953). Jack or Scots pine have also been suggested as nurse crops for white pine underplantings (Heiberg 1953), but care must be taken on light soils particularly to avoid suppression of the white pine, and overdense reproduction of the Scots pine. (Stiell 1959A).

Direct Seeding

Direct seeding of pine has many theoretical advantages, but many more practical disadvantages compared with planting. The advantages generally refer to the greater similarity with nature's way, and to greater economy. In practice, however, natural stocking is seldom ideal, and the cost per tree of establishing and cultivating a seeded forest may match that of a planned, planted forest. The seed and cotyledonous seedlings are relatively unprotected from rodents, birds, competition, and a variety of weather effects; hence the stocking, if successful at all, is generally erratic, requiring subsequent costly treatment.

REQUIREMENTS FOR SUCCESS

The majority of red and white pine seeding trials have been failures, but there are circumstances where seeding shows promise. Best seeding conditions for pine in the natural forest have been described as an area of light soil with adequate moisture, burnt over 1 to 5 years previously, and with a scarcity of competition (Leslie 1953). Further chance of success in the case of white pine would be gained by using stratified seed, confined to receptive seedbeds such as moist mineral soil or *Polytrichum* moss, sown during the natural germination period (Smith 1951). Some measure of rodent control using poisons, pelleting or screening, and timing to coincide with suitably moist weather conditions are advisable as well.

PREPARATIONS

Preparations for seeding may include treatment of the seed. Pelleting or "capsuling" with rodenticides, insecticides, nutrient compounds, organic matter, deliquescent and bonding substances, singly or in various combinations, is possible. The site may require some treatment to prepare suitable seedbeds and eliminate brush, namely burning, scarifying or ploughing (Shirley 1937, Logan 1951). Moreover, the timing of the operation must be carefully arranged. Rodent losses are less following spring sowing, but fall sowing results in prompter germination in the spring (Shirley 1937).

TECHNIQUES

Manual Spot Seeding

This procedure permits economical use of seed in selected, specially prepared spots. The spacing of spots and the amount of seed sown on each can be varied as desired. The spots can be prepared by scalping with a hoe or similar instrument, or by scuffing with a boot, depending on the conditions. If competition is severe, such as in hardwood or mixedwood stands, poor results may be expected ordinarily (Fraser 1952). Also success in spot seeding red and white pine seems to decrease towards the north, where the soil is colder and heavier (Leslie 1953). Considerable scalping would be necessary in such cases. On the other hand, in very dry sites, such as in jack pine cut-overs, exposure can be the limiting factor and spots should be sheltered (Logan 1951). Best results have been obtained on spots cleared to the mineral soil, seeded, then recovered with a light layer of soil (Thomson 1949, Horton and McCormack 1960).

Mechanical Methods

Ploughing furrows or disking in strips may facilitate seeding, either in spots along the narrow strips, or broadcast, and either by seed drill or by hand (Shirley 1937, Hawley and Smith 1954). Results of such methods with red and white pine have been erratic but are cheap and useful where quick, extensive reforestation is required, or where planting stock and manpower are scarce but seed is plentiful and cheap (Minckler and Chapman 1954).

A compromise between manual and machine methods exists in the seeding guns such as a hand probe developed by the Ontario Dept. of Lands and Forests, which permits the drilling of single seeds in selected spots (Leslie 1951).

Broadcast Seeding

Broadcast seeding is especially subject to all the disadvantages previously mentioned. Moreover, the difficulties, particularly the cost of obtaining sufficient seed, are great. Five to nine pounds per acre of white pine seed are thought to be required; the cost of the seed alone would approximately equal that of planting with nursery-grown stock. (Toumey and Korstian 1942). Nevertheless, success has been achieved. Manual broadcasting of both white and red pine on slash-burned pine cut-overs gave results ranging from good to poor depending mainly on weather conditions (Burton and Leslie 1956).

Aerial broadcast-seeding also shows promise, especially on extensive burned areas. This has been attempted in Ontario (Leslie, 1953) and in Maine (Westveld 1949). In the latter case an area burned in October was seeded by airplane the following February on top of two feet of snow over which more snow fell directly afterwards. Best results occurred on moderately burned rather than severely burned locations; 2,475 and 1,325 seedlings per acre were obtained from sowing densities of 8,000 and 4,000 seeds per acre respectively.

APPLICABILITY

Summarizing, the chance of success with direct seeding of red and white pine on a reasonable scale is small. At present the chief issue in seeding is its cost relative to planting. The planting of cheap 2-0 or even 1-0 stock can give better results under certain comparable circumstances (Horton and McCormack 1960). Perhaps until better techniques have been developed, seeding may be most useful as a secondary measure, in conjunction with natural reproduction of existing desirable species, or with treatments such as scarification, brush spraying, or controlled burning.

STAND IMPROVEMENT

This section deals with pine silviculture during the period from the establishment of the stand to the reproduction stage preceding harvesting. The various treatments involved, frequently termed intermediate cuttings, are dealt with under the categories of cleaning and improvement cutting, thinning and pruning. Control measures up to the sapling stage of stand development are considered as cleanings and liberation or release cuttings. In older untreated stands, particularly mixedwood or irregular stands which have resulted from irregular wildfire, hi-grade logging, and disease or insect damage, similar measures are termed improvement cutting. Comparable treatments in evenaged pine stands are referred to under "Thinning".

Cleaning, Liberation and Improvement Cutting

AIMS AND EFFECTS

Both pines are commonly subjected to suppression from a tree canopy and from competing subordinate vegetation. This is a normal occurrence in natural stands, particularly mixedwood types, and is frequent in poorly managed plantations. Control of this competition is essential to the maintenance of vigour in the pines, which are usually the desired crop species in such cases. Control may also encourage the establishment of more pine reproduction, but this is not the principal aim.

The objectives of these classes of cuttings are improvement of stand composition and quality, and liberation of crop trees. In natural stands this will usually involve the removal of competing hardwood species, pine wolf-trees, and diseased or deformed individuals, plus the thinning of overdense pine clumps and perhaps the elimination of overtopping shrubs locally (Hawley and Smith 1954).

Improvement cutting is one field of forestry where art transcends science. No two stands and few economic conditions are alike, so that flexibility is essential. Poor application may result in such undesirable effects as understocked stands and irregular age structures. Leads to appropriate applications may be found in the succeeding accounts.

EFFECTS OF COVER

Up to a point, overhead cover is advantageous as a nurse crop for young pine. The point varies with site—the drier the site the more beneficial the cover to the establishment of pine (Anon. 1939, Young and Eyre 1936). It also differs with the species, since white pine is more shade-tolerant than red. Relative percentages of full sunlight required by the two species in plantations have been given as follows (Rudolf 1950):

	At Planting	Years After Planting		
		1–5	5–10	10–15
Red Pine	30–35	50–60	70–80	80–100
White Pine	25–30	40–50	50–70	75–90

There may be other advantages in cover, such as protection from weevilling in white pine, and from abnormal weather effects (Miller 1934, Stiell 1959B). A common disadvantage of cover to the pines, in addition to suppression, is whipping damage.

RESPONSE TO RELEASE

The capacity to respond to release from competition is strong in both pine species. The response is proportional to the amount of cover removed and to the amount of suppression, so that the trees suppressed most will benefit most. Diameter growth responds faster than height growth (Miller 1934, Young and Eyre 1936, Downs 1943). In one case the cutting of merchantable (6″ d.b.h. and over) trees of a 70-year-old canopy of jack pine and aspen which suppressed a 40-year-old red and white pine understorey caused an increase in net current annual increment from 1.1 to 4.5 per cent, almost all of it on the pine understorey (Robertson 1945).

This ability to recover from suppression is maintained for many years. Red pine badly suppressed up to 40 years by hardwoods has greatly increased in height growth after release (Ralston 1953). Stem analyses of pines released naturally from suppression in mixedwood stands show that their responding growth rate can be greater than that of unsuppressed pines in the same condition (McCormack 1956).

Figure 24. White and red pine suppressed by aspen and requiring release.

TIMING APPLICATIONS

Cleaning in evenaged stands can commence any time after the initial protection period, preferably before the effects of suppression or whipping become marked. The expenses of control increase as the competition grows larger, but it may be advantageous to delay cleaning until the young pines are large enough to outgrow new sprout or sucker growth of hardwoods and shrubs which may evolve (Young and Eyre 1936, Hawley and Smith 1954). White pines one foot tall when cleaned become overtopped again in two years, and it may take them two or three years to recover from suppression. If cleaning is delayed until they are five feet tall and about 20 years old they may not require further release (Engle 1951).

Improvement cuttings are, in effect, retarded cleanings, and since they involve the removal of undesirable dominants, the sooner applied the better from a silvicultural viewpoint (McCormack 1956, Hawley and Smith 1954).

INTENSITY OF TREATMENTS

The appropriate amount of release cutting to be applied depends on local considerations. Primarily it is a question of economics—the relative end values of the competing species and the suppressed pine, and the net operational costs (Rudolf 1950). Later improvement cuttings can, if markets are available, pay for themselves (Wile 1955).

The cutting may range from removal of the complete canopy to overhead release of a relatively few selected understorey pines for crop trees; 150 trees per acre (spaced at a 17-foot average interval) has been suggested (Hawley and Smith 1954). Complete release in one operation is often inadvisable. It may result in greatly increased vegetative competition in the form of weeds, suckers, and sprouts (Young and Eyre 1936, Rudolf 1950), a tendency to poorer form (Hawley and Smith 1954), damage from exposure and, in white pine, more weevilling (Miller 1934, Young and Eyre 1936).

If several cleanings are envisaged, the first should be heavy and the subsequent ones progressively lighter so that the vigour of the crop trees can increase at an optimum rate (Hawley and Smith 1954).

METHODS OF RELEASE

Cutting and Girdling

Cutting is one obvious method of release, useful where the trees to be removed are merchantable and where sprouting is no problem. Stems with a diameter up to 6 inches can be efficiently cut by axe or other hand-cutting tools, or by powered brush-cutter saws (Stiell 1959B). Larger unmerchantable trees may be more cheaply eliminated by girdling, using a power saw equipped with a kerf-tooth chain (Stoeckeler and Arbogast 1952) or a special girdling tool.

Suckering and sprouting may cause the competition after cutting to be worse than before. Remedies for this might be releasing in stages, thus maintaining enough shade to deter sucker growth (Geerink *et al.* 1954); or cutting aspen in summer rather than winter (Stoeckeler 1947, Worley *et al.* 1954).

Figure 25. An over-dense natural stand of young red pine. Cleaning is required, along with removal of the scattered overstorey.

Chemical Herbicides

Another method which will effectively kill and prevent sprouting of deciduous species is through chemical herbicides, which can be used alone or in conjunction with cutting or girdling. The most popular chemicals used for such purposes are ammonium sulphamate (Ammate), and the hormone compounds 2,4-D and 2,4,5-T which are usually applied in solution or emulsion with water or oil (Suggitt 1952, Rudolph 1951, Sutton 1958, etc.).

There are several techniques for applying herbicides—foliage spraying during the height of the growing season (Rudolph 1951, etc.), basal bark spraying at any season (Arend 1953, Atkins 1956, McQuilkin 1957), frill girdling and notch poisoning during growing season (Peevey 1949, Smith 1951, Day 1948, Arend and Coulter 1953), and stump spraying immediately after cutting (Rudolf 1951).

The most suitable method, chemical, and concentration will depend on the size, density and composition of the vegetation to be treated. Dense brush, shrubs, and small trees require foliage spraying. An emulsion of 2,4-D or 2,4,5-T in water at 3,000 p.p.m. will effectively kill the brush without harming the pine (Atkins 1956, Rudolf 1951, Suggitt 1952), but a mixture at 5,000 p.p.m. (3 lbs. 4 ozs. of acid equivalent per gallon) can be harmful to young white pine reproduction (Atkins 1956). Also, spraying early in the growing season (June and early July) can damage new growth in young red and white pine (Anon. 1954). Good results in release and establishment of red and white pine reproduction have been achieved with dosages of up to four pounds (Hansen 1953) and as

little as one pound (McConkey 1956) per acre. Spraying by airplane or helicopter holds promise as an efficient means of releasing large areas of suppressed pine reproduction (McConkey 1956).

Larger unwanted trees can be killed by frill girdling and the application of 10,000 p.p.m. of a 2,4,5-T ester in oil (76.8 ozs. of acid equivalent per gallon) (Arend and Coulter 1953), or by basal spraying at 12,000 to 15,000 p.p.m. (Suggitt 1952). Basal spray at a concentration of one pint in 3 gallons of diesel oil has been found effective against aspen, hard maple, red maple, red oak, and balsam fir but not against white pine, or white and yellow birch (Atkins 1956). Aspen suppressing planted white and red pine have been successfully eliminated by the insertion of ammate crystals in notches cut at the stem base, although spring treatment caused some mortality of red pine in the vicinity of treated aspens (Anon. 1950).

Costs of chemical release will vary widely with the size and species of the trees to be killed and with the type and intensity of treatment required, but it will likely prove more efficient than manual release methods.

Thinning

AIMS AND EFFECTS

Stands of white and red pine are seldom so dense that a reduction in height growth comes about through mutual competition, but are frequently dense enough for diameter growth to suffer, implying a longer rotation requirement (Stiell 1959B). The remedy is periodic thinning, which is designed to sustain good growth, preferably redistributed on selected trees, and to increase total yield, largely through the reduction of natural mortality.

There are other beneficial effects of thinning. It may prevent crown breakage from accumulated snow and ice, to which close-canopied pine stands are subject (Mulloy 1946, Woodford 1949). It will improve stand hygiene through the elimination of weak and infected specimens. Also it will prepare the way for regeneration cuttings by developing vigorous crop trees better adapted to exposure and seed production (Hawley and Smith 1954). The increase in light, ventilation and precipitation within the stand improves the seedbed conditions, increasing decomposition of litter and humus, and development of tree reproduction and subordinate vegetation (Geiger 1950).

In addition to cost, which is usually the main deterring factor, the drawback in thinning may be the damage to residual trees possible through logging or exposure, the development of an undesirable understorey of vegetation, the increased fire hazard from slash, and the spread of insects and disease through slash and stumps (Hawley and Smith 1954). Excessive opening of the canopy can bring about soil desiccation and erosion as well as sunscald, windthrow, and breakage in the remaining stand (Hawley and Lutz 1943).

ECONOMICS

The applicability of thinning is generally influenced more by economic than silvicultural considerations. Happy are the circumstances where both are in accord. It is primarily a question of local markets, and in cases where these are readily available, thinning, properly managed, can provide profitable returns and excellent stands.

Figure 26A. A dense immature red pine stand before thinning.

Figure 26B. Same stand after two successive thinnings.

Early red pine thinnings may find a profitable market as posts or pulpwood. Other possible outlets for small material of both species would be as small logs, pit props, stakes, fuelwood (Cook 1949, Roe 1950), and Christmas trees (red pine tops). Larger thinnings are usually most valuable as sawlogs in the case of white pine, and as poles in red pine (Stiell 1959B). Exemplary cases of well-managed, profitable thinnings in older pine plantations are presented in some detail by Stiell (1959B). They include red pine plantations at Rockland, Ontario (Stiell 1953, 1957), Saratoga Springs, N.Y. (Luther and Cook 1948) and Starr Lake, Wisconsin (Wilson 1955); white pine plantations at Huntington Forest, N.Y. (Heiberg 1953) and Ann Arbor, Michigan (Spurr *et al.* 1957); and a mixed pine plantation in southern Ontario (Anon. 1952). Another notable example deals with natural red pine stands of Minnesota (Eyre and Zehngraff 1948), where the removal of 60 per cent of the total volume in thinnings was estimated to increase by 49 per cent the stumpage value during the rotation.

EFFECT ON STAND GROWTH

Studies in red pine plantations have provided much basic information on the effects thinning has on stand development. Thinning frees more of the crown, enables it to expand and hence increases the tree's photosynthesis. The response in terms of increased diameter growth is virtually immediate; a 41 per cent increase in 24 hours was recorded in one case (Stephens and Spurr 1947). Diameter growth after thinning may be doubled for years; an increment of two inches in 10 years may be possible (Engle and Smith 1950, Stiell 1953). It is more rapid at the base of the stem, so that greater taper develops.

The growth of the other main variables of stand mensuration—height, basal area and total volume per acre— is not appreciably affected by thinning within the range of stand density normally associated with the pines, and provided site, age and stand composition remain constant (Hawley and Smith 1954, Stiell 1959B). However, this does not apply in open or overdense stands. For example, stocking levels in a red pine plantation of 80 to 140 square feet of basal area per acre all gave about the same rate of volume growth, whereas levels of 60 and 160 square feet were less productive (Anon. 1956). In another case (Wilson 1955) height growth of dominant red pine became retarded at spacings closer than 15 per cent of the stand height.

MARKING PRINCIPLES

Two approaches to thinning can be distinguished (Hawley and Smith 1954). One emphasizes crop trees, the selection of high-quality individuals usually suited for sawlogs. The second concentrates on stand regulation for optimum total yield.

The marking of pine crop trees must be based on the natural processes of stand development. There is, barring accident, a progressive natural selection of the fittest trees in the stand, reflected by constant changes in the relative crown positions of individuals. At first most of the trees are more or less equal; then the weaker fall increasingly behind and cannot regain a dominant position. Thus the logical approach in thinning for quality production is to favour the most promising dominants of the desired species, reducing their competition. This is best done by removing nearby rejected dominants and codominants and poorly formed trees. Other lesser competitors, more distant or more suppressed, may be left at the early thinnings to put on growth (Stiell 1959B). It has been found that

the smallest 30 per cent of trees in a red pine-white pine stand contribute only 3 per cent of the total net growth and are therefore of negligible importance (Spurr and Allison 1952).

A useful aid in the marking of stands for thinning is a tree classification. One has been worked out for second-growth red pine, jack pine and aspen in the Lake States (Gevorkiantz *et al.* 1943) and involves relative crown position, crown density, soundness, form, and utility. Economic and ecological conditions vary so much, of course, that it is practically always necessary to adapt such classifications to particular needs.

THINNING CRITERIA

There are a number of ways of assessing the need for thinning in pine stands, as follows:

1. The live crown ratio—when it decreases to about 40 per cent in dominant crop trees of either pine species, a thinning is indicated (Hawley and Lutz 1943, Heiberg 1953, Woodford 1949).
2. The percentage of dominants and codominants in the stand—if the average stand diameter is 6 inches, stands with less than 60 per cent dominants and codominants should be thinned (Rudolf 1950).
3. Stand density index—a value derived from number of trees per acre (N) and average diameter (D) by the following formula: $SDI = N(\frac{D}{10})1.6051$. If falling, it indicates a density too high for optimum growth (Mulloy 1943, 1946A, 1946B).

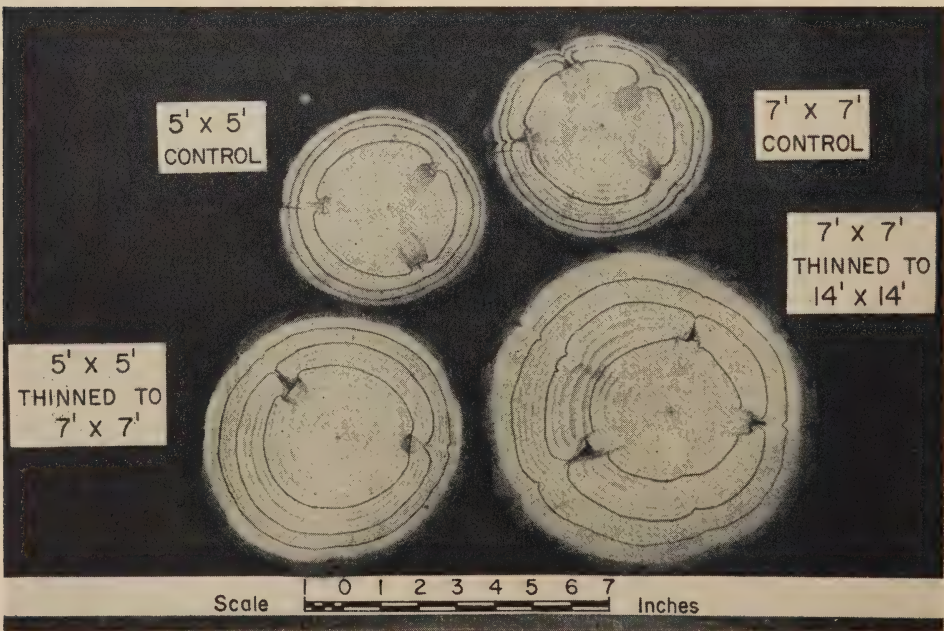


Figure 27. Cross-sections of planted red pines 33 years old, showing the effects of thinning at 17 years. Spacings are illustrated. The knot-healing process after pruning is also evident.

4. Number of trees per acre in relation to height—a formula is used to gauge the suitability of density as follows:

$$\text{No. of trees} = \frac{43{,}560}{(\text{f} \times \text{total height})^2}$$

where f is a fraction of total height, kept constant at about 1/5 in the case of red and white pine (Wilson 1946, 1955)

METHODS

Several of the recognized thinning methods have some application to pine.

Low Thinning

In low thinning the poorest crown classes are successively removed, usually around selected crop trees, until the desired reduction in stocking is reached. This method has been used in first thinnings of young pine plantations (Ralston 1954, Ward 1958). It is perhaps most useful in middle-aged stands, particularly of the more intolerant red pine, in which the subordinate classes are merchantable but lack the vigour to respond well to release (Hawley and Smith 1954). The merits of low thinning are its simplicity and similarity to nature's trend; its main disadvantages are the frequent unmerchantability of the small material removed and the fact that it does little to stimulate growth of the large crop trees.

Crown Thinning

This method avoids the above drawbacks through the removal of trees from the middle and upper crown classes, to favour selected trees of the same classes (mostly codominants in practice). Only the profitably merchantable lesser trees are cut; thus the immediate returns are much greater from this method. Also the remaining subordinate trees may serve to protect the stand and site, restrict lesser vegetation, and increase natural pruning in the crop trees. Crown thinning started early and applied lightly and frequently can give excellent results in red pine plantations (Hawley and Smith 1954). It has also been used to advantage in white pine after earlier low thinning (Ward 1958), although it is not recommended for stands which lack a satisfactory understorey of suppressed and intermediate trees (Hawley and Smith 1954).

A comparison of these two thinning techniques applied for 40 years at 5-year intervals to a white pine plantation is available (Spurr *et al.* 1957.)

Selection Thinning

In this method dominant trees are removed to stimulate the lesser classes. A classic application is in severely weevilled older white pine stands, where the deformed dominants should be cut to free potential crop trees presently in the lower classes (Hawley and Smith 1954). This has been done in New England by girdling the ruined dominants in two or more operations, releasing undamaged codominants and intermediates which are small enough for pruning (Cline 1931).

Mechanical Thinning

This general method refers to cutting by a predetermined pattern without regard for crown classes. One approach is *spacing thinning*, in which residual crop trees are at fixed intervals of distance. Average spacings of 20 per cent (Wilson

1955) and 25 per cent (Ralston 1954) of the dominant height have been recommended for red pine plantations. *Row thinning* is particularly useful in first thinnings of dense plantations. To facilitate logging in these conditions it is frequently the practice to remove whole rows selectively. Every ninth, eleventh or thirteenth row is commonly cut in Ontario plantations to provide skidding trails (Grinnell 1956), and there are cases in the U.S.A. where the removal of every third (Spurr 1947) and every fifth (Luther and Cook 1948) row has been considered advisable.

The most suitable method of thinning a stand will thus vary with the economics, logging practices, and silviculture of the situation. It may be desirable to alter methods in an irregular stand or in successive operations in a given uniform stand, according to changing developments.

Timing

In theory thinnings should be timed to forestall growth reduction through competition. The first thinning in an average-spaced (6 × 6 feet) plantation would therefore be required between 15 and 20 years, when the removed material would be largely unmerchantable. Since it is desirable to defray costs by selling the thinnings, the practice often is to defer the initial operation until this is possible, or to plant at wider spacings. At a spacing of 8 × 8 feet thinning can be left without sacrificing diameter growth until the stand is 30 years old at which time most of the material would be merchantable (Stiell 1959B).

Precommercial thinnings may be well justified if they prevent stand deterioration. A case in point would be the overdense, stagnated stands of natural red pine reproduction which occasionally occur (Schantz-Hansen 1952, Hawley and Smith 1954). White pine tends to express dominance even in dense stands (Deen 1933) and is therefore less susceptible to stagnation.

Regulation Practices

Several systems of regulating thinning have been worked out for both plantations and natural stands. They vary widely because they pertain to different regions and stand conditions and have different objectives.

Thinning Regimes

A series of thinning regimes has been set up for mixed red and white pine in five site classes, based on fully stocked natural and planted stands at the Petawawa Forest Experiment Station in Ontario (Smithers 1954). By this system which, it must be emphasized, pertains to optimum stocking, stands should be thinned starting at age 30, every 5 years up to 50, then every 10 years to 70, and lastly at age 85, aiming at a rotation of 100 years. It is also indicated that well-distributed thinnings of up to 30 per cent of the basal area may be made every 10 years without adversely reducing the gross increment.

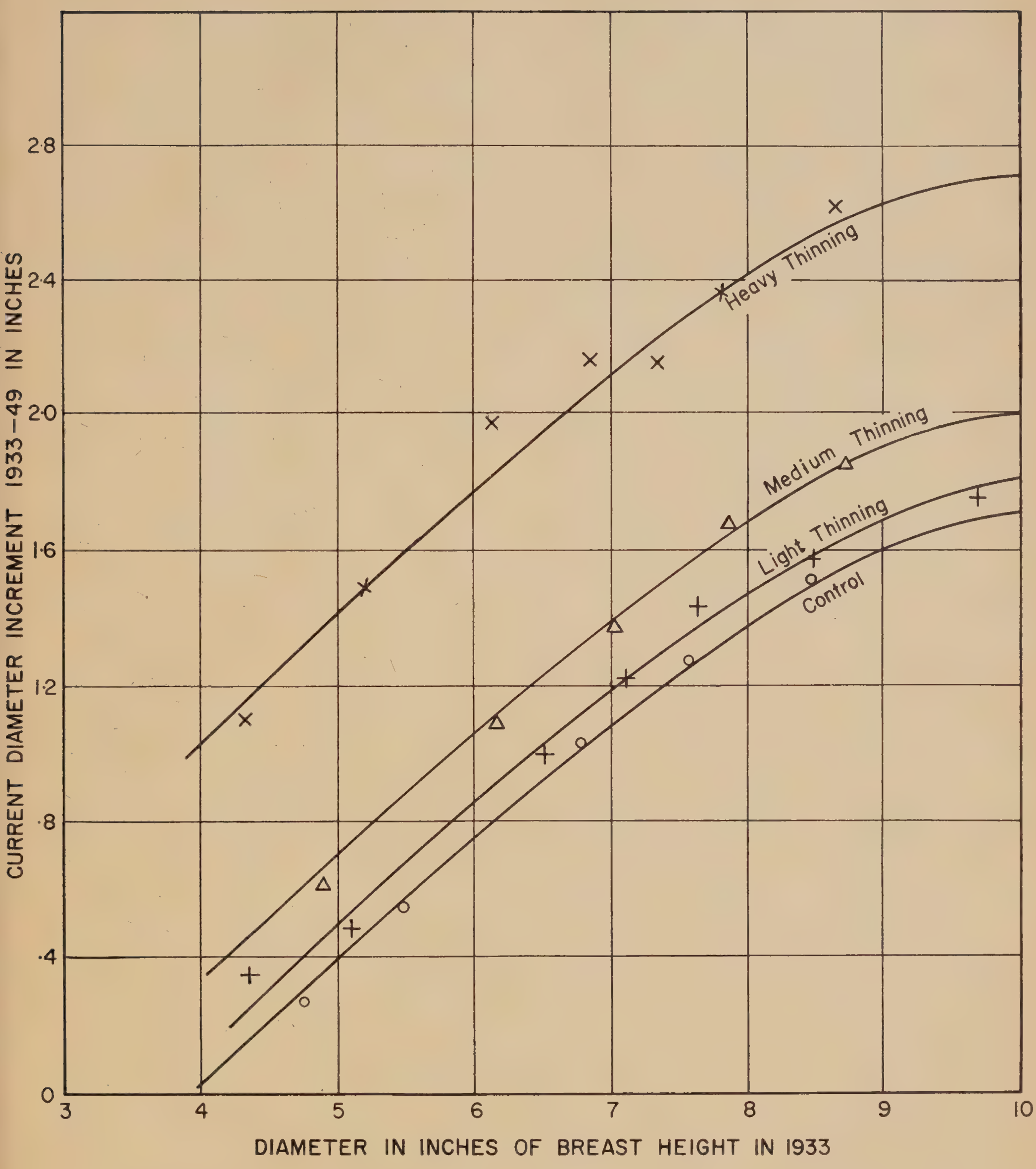
Another hypothetical system applicable to intensively managed red pine on average sites in Minnesota, consists of a precommercial thinning at 25 years, then commercial cuts every 5 to 10 years until shelterwood cutting begins at about 125 years (Eyre and Zehngraff 1948).

Spacing Systems

An approach applied in Ontario pine plantations involves thinning every 10 years to keep the basal area below 130 square feet per acre, which is supposed to be the point at which growth rate declines. Through a spacing formula, calcula-

FIGURE 28

DIAMETER GROWTH UNDER DIFFERENT THINNING INTENSITIES



The effect of intensity of thinning on diameter increment of red pine during the period of 54 to 70 years of age. Residual basal areas in square feet at different densities were: heavy thinning, 85 square feet; moderate thinning 111 square feet; light thinning, 142 square feet; control, 190 square feet.

(Smithers) 1954

tions are made for reducing the basal area to the point where 10 years growth will return it to 130 square feet (Anon. 1948). Another method is to compute the increment for each 10-year cycle and reduce the basal area a little below normal (based on calculated curves), allowing it to increase above normal by the end of the cycle (Grinnell 1956).

Still another procedure, worked out for red pine plantations in Wisconsin, involves thinnings starting after 30 years, coinciding with each added eight feet of height growth, and regulated to leave a residual spacing of 20 per cent of the dominant height (Wilson 1955).

Thinning for Quality White Pine Sawlogs

In managing white pine for high-quality lumber production in New York (Heiberg 1953), a constant diameter increment of one inch every 3 to 4 years is aimed at by maintaining a crown ratio of 40 to 50 per cent through frequent light cuts. This treatment applies to stands with an average basal area of 120 to 140 square feet per acre on good sites, and 80 to 100 on poor. A series of low thinnings in New England white pine showed that a residual stocking of 100 square feet basal area produced optimum growth and fully occupied the site (Hawley 1927, 1936). Lighter thinnings leaving about 125 square feet per acre resulted in less growth in the crop trees.

At the Pack Forest, N.Y., the procedure is to remove coarse wolf trees and blister-rusted trees early, cutting at 5-year intervals and developing as many high-quality white pines as possible (Foster and Kirkland 1949).

Thinning for Quality Red Pine Poles

Management of red pine for pole production requires stands of straight, thin-limbed trees. Plantations with spacings ranging from 5 × 5 to 8 × 8 feet have been found best for these requirements in Michigan (Guilkey 1958). Recommendations are to defer thinning until the average stand diameter is 4 to 6 inches, and the basal area more than 150 square feet, then to thin every 4 to 6 years down to 140 square feet basal area until limbs up to the height of the pole requirement are dead, after which heavier cuttings can be made down to 100 square feet. Maximum basal area growth in thinned red pine plantations in Ontario was found to occur at a residual basal area of 80 square feet (Stiell and Bickerstaff 1959).

Thinning Mixed Plantations

First thinning practices recommended in Ontario for average-spaced plantations of pine in alternated rows with other conifers are as follows (Grinnell 1956):

Red and white pine—the white pine are usually suppressed by 25 years; 75 to 125 well-spaced white pine per acre should be released as crop trees; some dominant red pine trees and even whole rows may have to be removed to favour the white pine; badly suppressed white pine rows may also be cut.

Red and Scots pine—the latter will predominate at about 20 years; they should be heavily thinned leaving some well-formed dominants but favouring the red pine.

Red and jack pine—the jack pine becomes dominant by 25 years on light soils and should be treated as recommended for Scots pine.

White and jack pine—again, on light soils the jack pine attains early dominance, by 15 to 20 years in this case; a precommercial thinning is required to release a select crop of white pine.

White pine and larch—the larch does not surpass the pine and can be thinned from below; badly weevilled white pines may also be removed.

White pine and white spruce—generally the white pine will predominate at first and may become weevilled; if white pine is to be favoured, thinning should be deferred until the spruce overtakes it; then the spruce may be selectively thinned to release pine crop trees.

Pruning

ECONOMICS

Both pines are relatively poor at self-pruning, and since clear pine lumber is up to 50 per cent more valuable than the highest grade of knotty lumber, artificial pruning is an important issue in pine management. This applies equally to both species. Although red pine is usually priced inferior to white, its technical properties in plantations more closely approach those of old-growth white pine than do plantation-grown white pine (Cook 1949). Thus pruned red pine plantations have as interesting a potential in lumber as white pine.

The ultimate value of pruning will depend on the amount of usable clear wood which it produces, the relative value of clear and knotty wood at harvesting, and the costs with interest compounded (Shaw and Staebler 1952). It is the first 16-foot log of a white pine that counts; it contains one-third of the total cubic volume of the tree but represents two-thirds of the total value in lumber (Heiberg 1942). Therefore the pruning is most profitable if confined to, or just above, the first log—perhaps even the first 12-foot log (Ralston 1953).

EFFECT OF TREE SIZE

The larger the diameter of the tree when pruned, the longer it will take to attain a satisfactory proportion of clear wood (Bickerstaff 1942). Studies in plantation pruning have shown that trees of four inches (Curtis 1939) or in some circumstances, six inches (Campbell 1956) diameter are the largest which can be pruned profitably. In one case it was found unprofitable to prune white pines greater than six to eight inches in diameter, trees which slow the pruning rate below 75 linear feet per man-hour (Cline and Fletcher 1928). Exceptions to this size limitation do exist, as in the case of the high pruning of elite white pine, outlined later under "Methods".

SPECIES CHARACTERISTICS

Neither of the pines will prune itself satisfactorily in a reasonable rotation. Even in dense maturing stands the trees exhibit poor natural pruning. The laterals on the lower 20 feet remain alive for about 15 years, and close spacing neither decreases the number of knots nor increases natural pruning (Paul 1938, Arend 1955). It has been estimated that self-pruning to one log-length takes at least 40 years for red pine and over 60 years for white (Hawley and Lutz 1943).

White pine is more difficult to prune than red. Its branches are more numerous per whorl, heavier, larger at the base, and have more side branches than those of red pine. Also the wood has more pitch and secondary whorls are common (Hawley and Clapp 1935). In both species the average diameter of the knots increases with height up to at least 20 feet (Paul 1938, Stiell and Bikerstaff 1959).

Figure 29. Red pine crowns in a fairly dense, 75-year-old stand, illustrating the restricted crown development and retention of branch stubs.

Figure 30. Crowns of white pine in same stand as above. Retention of dead branches is here even more pronounced.

SELECTION OF CROP TREES

Considering the expense of pruning, it should be confined to carefully selected crop trees, fast-growing trees with a minimum diameter increment of about one inch in three years. At this rate it takes white pine 30 years to grow an acceptable four inches of clear wood around the knotty core; and 50 years for six inches. Two inches of diameter growth should be allowed for bark and pitch pockets before clear wood forms (Hawley and Lutz 1943). The selected trees should also be well-formed —dominants in the case of red pine, and undamaged vigorous codominants or even intermediates in the case of white pine where dominants are frequently malformed through weevilling. The intermediates selected should be released before pruning (Cline and MacAloney 1931, 1935).

Usually, then, a moderately small number of trees are selected for pruning, from 75 (Curtis 1939) to 400 (Cline and MacAloney 1931) per acre. In Ontario municipal plantations the policy is to prune to 17 feet about 100 white pine or up to 150 red pine per acre (Grinnell 1956).

EFFECTS ON GROWTH

Growth is related to crown size and therefore may be reduced by pruning. The removal of more than 50 per cent of the live crown was found to reduce height growth of young white pine by one-third (Hawley 1935), and removal of 50 to 70 per cent of the crown significantly decreased both height and diameter growth of red pine (Ralston 1953, Slabaugh 1957, Stephens and Spurr 1947, Bickerstaff 1941).

White pine in which $\frac{1}{4}$ to $\frac{1}{3}$ of the number of live whorls had been pruned slowed 8 per cent in diameter growth compared with unpruned trees at the end of 5 years, but the difference disappeared after 8 years, when the live-crown ratios of treated and untreated trees had become equalized (Barrett and Downs 1943, Downs 1944). Recovery of height and diameter growth in red pines, after 50 per cent of the crowns were removed, took only 4 years (Slabaugh 1957).

Thus it seems safe to prune up to *half the height* of the tree (Cline and Fletcher 1928), or up to *45 per cent* of the *live crown* (Woodford 1949). Another approach is to remove only those live branches which do not receive direct sunlight (Hawley and Clapp 1935). Pruning slightly in excess of these limits will cause a small, temporary reduction in growth, but it may be justified where economics dictate that one log-length should be pruned in one operation (Barrett and Downs 1943).

Pruning appears to have no effect on the bole form of red and white pine (Bickerstaff 1946, Barrett and Downs 1943).

HYGIENIC EFFECTS

Pruning should not in general promote the spread of disease in a tree; in fact the removal of dead branches will speed up the healing process of these normal sites of infection. The flow of pitch which results from the pruning of small live branches is usually effective in sealing off the wound (Hawley and Clapp 1935). Nevertheless, infection of stems by *Stereum sanguinolentum* Alb. and Schut. ex Fr., a wood-rotting fungus, can occur through pruning wounds, particularly large ones. Therefore live pruning should be confined to branches less than two inches in diameter, or those without heartwood (Sleeth 1938).

Close pruning of dead branches, involving the cutting of some live tissue at the stub's base, causes a flow of pitch which hastens the formation of callus advantageously (Curtis 1936, Adams and Schneller 1939), yet it also increases the risk of infection (Sleeth 1938).

The rate of healing is related to knot size and tree growth. It takes from 3 to 10 years for white pine stubs of ½ inch diameter to be completely covered (Hawley and Clapp 1935, Paul 1938, Campbell 1956), and 5 to 7 years for red pine (Paul 1938). Larger branches take proportionally longer.

SEASON

The timing of pruning in pine is not basically important but there are certain noteworthy considerations. During the growing season there may be excessive pitch flow which may cause pitch pockets, particularly in white pine, and in branches of more than one inch diameter (Cline and Fletcher 1928, Hawley and Clapp 1935). Winter is generally the most convenient time for pruning operations. Also the possibility of a market for the cuttings as Christmas greens may be worth considering (Stiell 1959B).

TOOLS

Important to the success of pruning is efficient technique. Axe pruning is seldom advisable in that it requires much skill to avoid damaging the stem. Shears may be necessary for the very small, pliable branches of dense young white pine plantations, but frequently leave a short stub. Ordinary clubs may be used to remove brittle dead limbs but there is the danger of leaving ragged stubs or tearing off live bark (Hawley 1935).

The most satisfactory tool is usually a saw, particularly a short, curved, handsaw. For working above the seven-foot level a polesaw may be used, but it is likely that a handsaw and ladder arrangement will give more uniformly good results with equal speed (Stiell 1959B).

METHODS

Pruning in Stages

In young plantations it is not possible to prune to one log-length without over-reduction of the crown, but it is possible to prune in stages, such as to successive heights of 7, 12 and 17 feet (Bramble and Schmidt 1951, Hawley and Clapp 1935). This method has the advantage of keeping the knotty core at a minimum and uniform diameter.

Deferred Pruning

Deferred pruning until the trees are tall enough to bear the clearing of a complete log-length is cheaper and improves the chance of selecting good crop trees, but results in a larger knotty core. For comparison, it has been estimated that a 16-foot red pine log with a 16-inch top diameter could be grown in an 80-year rotation; it would yield 75 per cent clear wood if pruned in three operations, and 66 per cent in one (Bramble and Schmidt 1951).

High Pruning

A method of high pruning larger thrifty white pine in natural stands has been developed at the Pack Forest in New York (Foster and Kirkland 1949, Foster 1953). It involves selecting about 25 elite trees per acre, pruning them to a maximum diameter of 12 inches and a height of 33 feet, and leaving them to develop to full maturity. One man can prune an estimated 40 trees per day in this manner, and the expected increase in lumber value is 5 cents per board foot.

Debudding

This is another form of pruning—bud pruning. It involves removing the lateral buds from each year's terminal shoot, starting when the tree is about four feet tall. No branches are allowed to form; growth is sustained by the lower branches and stem foliage. The procedure is stopped when one log-length is reached, and normal branching commences above that point.

In one experiment with planted red pine in Ontario, 17 feet of clear stem was thus obtained in 10 years. Debudded trees had an average diameter of 2.7 inches compared with 3.8 inches on untreated trees. Height growth may also have been decreased. The method is probably more expensive than normal pruning but the large amount of clear wood in prospect may justify it. It is recommended only for fast-growing plantations in good sites, with a spacing of 8 to 9 feet (Bickerstaff 1945, 1952.)

White pine appears to be less subject to reduction in height growth through debudding than red pine, but requires more time for the operation. After debudding, white pine develops many adventitious buds along the main stem (Fox 1957).

Figure 31. Debudding red pine at the Petawawa Forest Experiment Station, Ontario.

HARVEST CUTTING AND REPRODUCTION METHODS

Introduction

At the end of the rotation comes the period when the pine stand must be renewed. There is a variety of means for accomplishing this, involving silvicultural cutting of the mature trees, seedbed preparation for the encouragement of natural reproduction and, if necessary, artificial regeneration procedures.

Though many reproduction methods have been developed to meet different requirements (and practically every forest stand is different in some respects, ecological or commercial), they can be placed into a few standard arbitrary classes based on different principles. These provide a convenient point of departure for discussion. They may be distinguished first according to whether they produce even-aged or uneven-aged stands. The former involve regeneration cuttings concentrated at the end of the rotation; the latter, reproduction cuttings extending throughout the rotation. Because red and white pine are moderately intolerant of shade and most stands are even-aged in the first place, it is the even-aged management approach that is generally most applicable.

Cutting methods alone may not successfully restock an area to pine. Supplementary measures may be necessary, including slash disposal, brush, rodent or insect control, and ground treatment such as mechanical scarification or broadcast burning. Fire does all of these things, but is not a popular tool in red and white pine forests; substitutes must usually be found. Applications of these various techniques are considered in connection with cutting methods for which they are pertinent. The field of chemical control of unwanted vegetation has already been dealt with under release cuttings.

In the following pages the term "adequate stocking" is sometimes used with reference to pine reproduction. This is, of course, a variable concept, depending on objectives and conditions, but in general a figure of about 1,500 established seedlings per acre is considered reasonable for acceptable stocking of both red and white pine at later stages in stand development (Zon 1912, Hawley 1936).

Clearcutting Method

principles

This is the most straightforward method of producing even-aged stands since it involves complete clearing of the old stand, relying upon artificial regeneration or on natural seeding either from adjacent or cut trees. It is applicable only where practically all the trees are merchantable and one cut is most economical. Since there are usually some unmerchantable trees in any stand, some girdling or poisoning may be necessary—a possible disadvantage. However, the economic advantages generally well outweigh this; clearcutting provides the cheapest logging and the simplest planning of all harvesting methods.

The method should be avoided under certain conditions, such as steep slopes subject to erosion (Hawley and Smith 1954, Sowers *et al.* 1956) and excessively dry or exposed sites where germination and survival of seedlings would be in question. On the richer or moister sites of most regions, competition from hardwoods and other vegetation usually makes this method impracticable for pine (Lutz and Cline 1947, Chapman and McGowan 1954, Scott 1958, McCormack 1959). Also there are areas where it should not be applied for aesthetic reasons.

Clearcutting lends itself better than any other method to efficient slash disposal, ground preparation and competition control. Through such treatments, conditions can be created which emulate those in which most existing natural pine stands originated, namely after wildfire (Maissurow 1935).

Burning

Broadcast burning might be the silvicultural panacea. It may in one operation effectively eliminate or reduce slash, undesirable humus, litter, weeds, brush and trees (including *Ribes*, the blister rust host), all injurious insects breeding thereon, and seed-eating rodents, thus preparing in every respect for regeneration. But it is not a popular silvicultural measure in the northeast, and trial examples are rare. One, carried out on limited strips in a white pine cutover area at Temagami, Ontario, showed interesting although variable results (Burton and Leslie 1956). Given a ready seed supply and favourable subsequent weather, a light burn was found best for pine reproduction on poorer sites. Better sites supporting mixedwoods required heavier burning to reduce underbrush. Depth of burning varied widely with the season, summer fires penetrating deepest, fall fires slightly less so and spring fires scarcely at all; thus spring burning can encourage rather than reduce competition. Red pine seemed to require a heavier burn than white pine for successful reproduction.

It is pertinent to note that red pine, particularly at maturity, is more resistant to fire because of its thicker bark than is white pine (Hawley and Smith 1954), a point to be considered in planning controlled burning with a view to natural seed supply.

An alternative to broadcast burning is *slash burning in piles*, advocated for larger clearcut areas of white pine (Fisher and Terry 1920, Lutz and Cline 1947), as well as for strip, seed tree and shelterwood cuttings (Lutz and Cline 1956, Larsson 1946, Frothingham 1914).

Scarification

Ground scarification using mechanical equipment such as disks, plows or bulldozers is another alternative in pine site preparation (Burton and Leslie 1956, etc.). It is frequently advocated in conjunction with partial cutting methods but can be more efficiently carried out in clearcut areas. It may be preferable to burning in areas where there is heavy brush and little slash. More details on scarification are given under "Seed Tree Method" and "Shelterwood Method".

CLEARCUTTING AND ARTIFICIAL REGENERATION

This is the easiest of all methods for controlling composition, arrangement and stocking level of the next stand. But it is the most expensive in terms of initial cash outlay. The artificial regeneration is most applicable in larger clearcut areas where natural seeding cannot be relied upon.

Techniques

Regeneration should be established shortly after the cutting so as to compete well with the early flush of weeds and other vegetation, particularly if no ground preparation measures are contemplated. In many cases slash disposal will be necessary to facilitate the operation of planting or seeding. With seeding, as mentioned before, slash burning may greatly increase the chance of germination

as well as survival. In lieu of burning, disking or plowing would frequently aid planting or seeding. Planting and seeding techniques and their applications on logged areas have already been covered in the section "Artificial Regeneration".

Applications—Pure Pine Stands

In older pine stands of high value it may be more economical to cut all trees and plant rather than reserve valuable trees for seed. Also in good-quality but overdense mature pine stands all trees should be cut to avoid heavy windthrow losses (Hawley and Smith 1954). Again there are low-value stands such as open, badly weevilled, white pine stands where it is more profitable and silviculturally desirable to clearcut and plant (Hawley and Clapp 1942).

Extensive pine cutover areas which have not regenerated are common in the northern sections today, and an experiment at Temagami, Ontario (Burton and Leslie 1956) points to a possibly effective treatment. It involved broadcast burning of pine slash, followed by either spot or broadcast seeding of white pine, red pine and white spruce. The results, particularly in broadcast sowing, varied widely with the weather conditions, but there was sufficient success to show promise.

Applications—Mixed and Hardwood Stands

As well as a harvest method for pure pine stands, clearcutting with artificial regeneration can be effectively applied in low-quality mixedwood or hardwood stands, to replace the undesirable elements with productive pine or other species. For example, aspen stands have taken over vast areas of former pine lands in the Lake States, and to remedy this Shirley (1941) has recommended clearcutting the aspen, followed by disking or plowing, rabbit control measures, planting or seeding of pines, and subsequent cleanings if necessary. This is a costly procedure but the alternative loss in productivity of such lands is perhaps more costly.

Clearcutting supplemented by planting of vigorous (4 to 5 year) white pine stock has been broached as the possible answer to reintroducing the species on richer, cutover, tolerant hardwood sites which formerly supported scattered pines (Lutz and Cline 1947, Burton and McCormack 1950, McCormack 1959). Competition from the hardwoods on these sites is such that other pine reproduction methods are precluded, and only very intensive silviculture would maintain satisfactory development of the planted pine. Applied generally, such plantings have not been successful, because the seedlings have been rapidly suppressed. However, they will thrive exceptionally well on favourable spots where competition is reduced, such as drier knolls, old skidding trails and landings. This prompted Lutz and Cline (1947) to recommend that groups of white pine, less than $\frac{1}{5}$ of an acre in size and dense (to offset weevilling), be thus developed selectively in hardwood stands, and be cleaned or released as required.

Thus there are a number of important situations where the method of clearcutting plus artificial regeneration is especially suitable. As with other approaches, however, it need not be applied alone but may be supplementary. In practice it will continue to be used where other natural reproduction methods have failed.

CLEARCUTTING WITH NATURAL REPRODUCTION

With this method, seed availability is the main issue. Cuttings may be arranged to take advantage of seed sources from the side, or from the cut trees, or both. There are three variations of the method, and each will be considered separately.

Clearcutting the Whole Stand

In large clearcut blocks, seed from the side cannot be relied upon because in both pines it is relatively too sparse and heavy for adequate dispersal. For success, it is essential that the cutting operation coincide with a good seed crop, either just before or after it falls. Some viable white pine seed may remain stored for a while in the duff, but not enough to be relied upon. However, it should be pointed out that seed of some undesirable species, such as *Ribes*, can remain dormant for many years (Hawley and Smith 1954).

There have been several advocates of this method for white pine under certain conditions (Frothingham 1914, Fisher and Terry 1920, Lutz and Cline 1947, Maissurow 1935) but none, apparently, for red pine. In New England it was considered especially suited to areas of about four acres, with an adjoining white pine seed source. (Frothingham 1914, Fisher and Terry 1920). Two other features were unanimously considered essential—coincidence of cutting with a good seed year, and slash burning, either in piles or broadcast. Under these circumstances this can be the cheapest method of harvest cutting and stand regeneration (Frothingham 1914), except on the richer, fresher sites where competition from deciduous vegetation is excessive (Lutz and Cline 1947).

Clearcutting in Patches or Strips

These are modifications of the clearcutting method involving smaller clearings which can take advantage of seed from the side. They represent a compromise between clear and partial cutting in such respects as operational and planning costs, seed availability and seedling protection.

Figure 32. Successful white pine reproduction on a one-chain strip cutting in mixed pine, 15 years after cut, Petawawa Forest Experiment Station.

Techniques

The size of the clearings will vary with the height of the seed trees, as considered in the section on seed dissemination. In general the openings should be about twice as broad as the height of the timber (Hawley and Smith 1954). Their orientation should take into account the prevailing wind direction at seeding time, and the topography, with a view to efficient logging.

Both systems can be arranged to cover an area over any given period but usually two cuttings are applied, at an interval of from 3 to 10 years. The second cutting removes the seed source, and hence must be timed with a seed year if clearcut. Otherwise artificial regeneration or the seed tree or shelterwood methods would be necessary. This problem may be minimized by removing more than half of the stand in the "uncut" strips during the first operation, leaving enough timber to provide windfirmness and an economic second cut (Hawley and Smith 1954).

Clearcutting in patches is useful in irregular or uneven-aged stands or on rough terrain. It is advantageous in that the first cutting can be done where most necessary, such as in patches of overmature or weakened trees, on sites subject to windfall, and where advance-growth pine needs releasing. However, in uniform conditions strip cutting is generally preferred, being more easily adapted to systematic management.

Applications

Strip and patch cutting have been applied or recommended for white pine (Frothingham 1914, Fisher and Terry 1920, Scott 1958), red pine (Woolsey and Chapman 1914) and mixed pine (Fraser and Farrar 1955, McCormack 1959) stands under a variety of conditions. On poorer, drier sites, abundant white pine reproduction usually results without further treatment (Fisher and Terry 1920, Fraser and Farrar 1955), but on better sites the restocking may be poor unless ground preparations or brush control are carried out. Costs of logging and slash burning can be considerably lower in strip cuttings than in shelterwood cuttings on comparable conditions (Lutz and Cline 1956).

Fisher and Terry (1920) described an application in white pine stands of the patch cutting method, using patches 50 to 100 feet in diameter, which gave slightly better results than a comparable strip cutting. Reproduction of white pine on the drier sites was good, but on the better sites, poor.

Clearcutting in alternate strips has been successfully applied in white pine stands in New England, the strips being 80 to 200 feet wide, placed on the leeward side of the stand (Fisher and Terry 1920, Lutz and Cline 1956). On flat areas the strips should be laid out crosswise to the prevailing wind but on irregular terrain this may not be practical (Frothingham 1914). Alternate clearcutting has also proven satisfactory in mixed pine stands on light soil in Eastern Ontario (Fraser and Farrar 1955). Both one and two-chain-wide strips were cut at right angle to the prevailing wind, and the intervening timber was subsequently partially cut to encourage reproduction. Stocking and seedling development of white pine were superior on the one-chain strips; also weevilling and deer browsing damage was much reduced thereon.

In view of their versatility in application these "partial" clearcutting techniques are very useful. They are particularly well suited to stands which require a compromise between clearcutting with its economy and simplicity, and

shelterwood cutting with its protection for residual timber, seed supply, and regeneration. Previously untreated natural stands of either pine species fall into this category.

Seed Tree Method

PRINCIPLES

In this method the stand is clearcut except for a small proportion (less than 10 per cent by volume) of trees, left standing singly or in groups. These "seed trees" may or may not be removed after regeneration is established. They are too sparse to provide protection for the seedlings as in the shelterwood method.

The seed tree method can give satisfactory pine reproduction under some circumstances, applied either directly together with site preparation, or as a supplementary measure. It has the advantages of clearcutting in being cheap, simple, and conducive to broad site preparation, yet it provides more assurance and more control of regeneration than clearcutting can give. At the same time it has significant disadvantages—exposure of the site and regeneration, susceptibility of the seed trees to windfall and other damage, and the problem of utilizing the seed trees economically.

SELECTION OF SEED TREES

The most important point in application is the choice of seed trees. First they must be windfirm. Actually both pines, by virtue of their deep, often complex root systems are relatively wind-resistant on most sites. However, white pine is subject to stem breakage, a major disadvantage in this connection. The most windfirm individuals are those with relatively short, stocky, well-tapered stems and deep crowns. These characteristics are not to be found in dense stands but can be developed by selective thinning at early stages. Such trees are also usually

Figure 33. A good red pine seed tree.

Figure 34. A good white pine seed tree.

good seed producers. This brings us to the second main point in selection, namely, to guard against reserving inferior trees which will result in genetic deterioration and poor restocking (Hawley and Smith 1954).

DISTRIBUTION OF SEED TREES

Next comes the question of how many seed trees to leave. As stated under "Seed Dissemination", pine seed can travel up to 900 feet but usually is limited within a distance comparable to the tree's height. Moreover, cross-pollination is effective only for 100 to 200 feet, so that 2 or 3 seed trees per acre would be inadequate. There are other factors involved in this question, such as the amount of viable seed produced per tree, which depends in turn on the original stand age, density and vigour; also the relative susceptibility of the seed trees, the seed, and the seedlings to destruction.

McCormack (1959) advocates leaving from 5 to 30 seed trees of either species per acre, varying with site and treatment (see Table 9). With more than 10 trees left, however, the condition begins to approach a shelterwood cut, as Hawley and Smith (1954) point out. Others are less liberal, suggesting a general figure of 4 trees per acre distributed as uniformly as possible or, for more windfirmness, small groups of trees spaced approximately 200 feet apart (Frothingham 1914, Larsson 1946). This may be enough for white pine but not for red pine according to Woolsey and Chapman (1914), who maintain that up to 10 trees per acre are needed, and the more the better.

APPLICATIONS

The seed tree method is a controversial one with respect to white and red pine. It appears to have as many advantages as disadvantages, which reflects its intermediate position between the partial and clearcutting systems.

Red Pine

Many cases of this method's failure in red pine can be attributed to inadequate seed supply and seedbed. Unless conditions are ideal—unless logging coincides with a good seed year and is followed by ground disturbance through fire or scarification—seed-tree cutting will not likely work with red pine, which has neither the abundance of seed nor the dispersal distance ordinarily required (Zon 1912, Woolsey and Chapman 1914, Eyre and Zehngraff 1948). Damage from windfall and sunscald add to the debit (Woolsey and Chapman 1914). It is evident that the method is particularly unsuitable for previously untreated, dense, natural stands.

White Pine

The above drawbacks may be offset by the use of supplementary treatments and by the avoidance of sites susceptible to damage. Thus various measures of brush control and ground preparation have been recommended in conjunction with seed tree cutting in white pine. Larsson (1946) advocates mechanical or chemical brush control combined with slash burning where necessary; Frothingham (1914) suggests a light broadcast burn after logging but before the seedfall of a good crop, providing the seed trees can be sacrificed; McCormack (1959) presents a detailed list of sites (Table 9) on which mechanical ground scarification combined with variable seed tree cutting will likely provide acceptable regeneration of either white or red pine. This latter approach has provided satisfactory

white pine regeneration on moderate till sites in western Quebec which otherwise would have developed only brush (Krewaz and Horton 1959). Scarification was carried out by a bulldozer with an ordinary blade used intermittently to provide about 50 per cent disturbance of the ground.

General

In general the seed tree method is best adapted to extensive forestry in that an unlimited area can be cut at once. This perhaps explains why it is advocated for the mature "virgin" white pine stands of Ontario and adjacent Quebec (Larsson 1946, McCormack 1959). It was formerly used in the red pine stands of the Lake States but has now been supplanted by the more intensive shelterwood methods which assure adequate seed supply and seedling protection (Eyre and Zehngraff 1948). In other conditions, such as the white pine stands of New England, clearcutting and shelterwood methods have proven better (Fisher and Terry 1920, Hawley and Smith 1954).

Even in a stand which has adequate advance reproduction or one in which artificial regeneration is contemplated, it may be advisable to employ the seed tree principle as insurance against fire or other catastrophe in the young stock (Hawley and Smith 1954, McCormack 1959). And where extensive clearcutting in unregenerated timber is believed necessary for economic reasons it is essential that seed trees be left and that cutting coincide with a seed crop (Candy 1939, etc.)

Figure 35. Seed tree cutting in a mature pine stand in western Quebec. Followed by ground scarification, this method produced good white pine reproduction.

For many years in Ontario and Quebec a 13-inch diameter cutting practice prevailed. This was better than wholesale clearcutting since it left some seed trees, but rigid application meant that the seed source was all too frequently inadequate in quantity and quality. A proper seed tree cutting should ensure that a few of the good trees rather than a number of poor ones remain.

Shelterwood Method

PRINCIPLES

This is, in general, the most appropriate reproduction cutting method for white and red pine under intensive management, in highly valuable, accessible forests with ready markets. It is considered the system which best provides the required sequence of conditions for the development of white pine reproduction in particular, namely, receptive seedbed conditions, an abundant seed supply, protection during initial seedling establishment, and finally, release (Smith 1951).

The method provides reproduction under the shelter of the old stand by means of partial cuttings resembling thinnings. The first operations, termed "preparatory cuttings", are aimed at encouraging crown development (hence seed productivity) and at improving seedbed conditions; following this are "seed cuttings" which promote the establishment of regeneration; lastly, when the restocking is adequate, comes the removal cutting which releases the regeneration.

APPLICATIONS—WHITE PINE

The uniform shelterwood system is ideally adapted for following an intensive thinning program in white pine (Hawley 1936, Foster and Kirkland 1949, Spurr *et al.* 1957). In New England only two or three shelterwood cuttings are

Figure 36. First stage of a uniform shelterwood cutting applied in a maturing white pine stand on a moderately good site in Eastern Ontario.

required (Frothingham 1914, Fisher and Terry 1920, Lutz and Cline 1956). Frothingham (1914) advocates that the first cutting should coincide with a good seed year, should be heavy, removing about half of the trees to favour selected dominants, and should provide soil disturbance through the logging operation. The removal cut should take place shortly after the succeeding seed crop before suppression becomes evident among the regeneration, and should occur in the winter to minimize damage to the established seedlings. Slash should be lopped and scattered or piled and burned. It may also be necessary (Foster 1953) to release pine regeneration from brush competition by, for instance, periodic sprayings of herbicides. Scott (1958) suggests the possibility of prescribed burning following shelterwood cutting on sites where competition against white pine reproduction is strong. Subsequent cleanings would be required as well.

MODIFICATIONS—WHITE PINE

Lutz and Cline (1947), dealing with a series of cutting method trials in white pine on medium-quality sites at the Harvard Forest, report successful reproduction from a *strip shelterwood* system which involved a strip 50 feet in width, cut along the stand margin six years after a thinning. Another trial suggested that the *group shelterwood* method is equally applicable. In this case there were groups of natural white pine reproduction before treatment began. First all hardwood advance growth was removed, then half of the pine trees

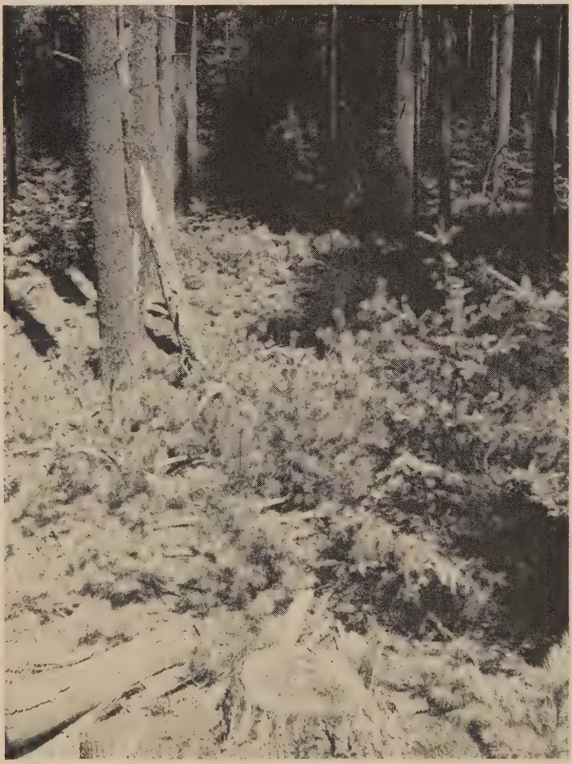


Figure 37. Abundant white pine regeneration resulting from a group shelterwood type of cutting in pure pine on a sand terrace.

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(one-third of the volume) in a uniform thinning, succeeded by a similar thinning of half the remaining trees three years later. The final cutting took place after six more years, at which time the regeneration groups were well developed and scattered seedlings occurred between them.

The group shelterwood approach applied in winter for the protection of advance growth or, if necessary, in combination with ground scarification is recommended by Sowers *et al.* (1956) for mixed white pine stands in the Alleghenies. It has also, along with uniform shelterwood cutting, been used for white pine in eastern Ontario (Horton 1958).

Another variation is the *irregular shelterwood* or *shelterwood-with-standards* method, which is characterized by a long regeneration period in which some of the overwood trees which are particularly valuable are retained to grow to optimum size. A classic case of this technique is at the Pack Forest, N.Y. (Foster and Kirkland 1949, Lockard and McQuilkin 1959), where selected, pruned white pines (about 25 trees per acre) are reserved well beyond the usual rotation age to put on quality growth. The value increment on treated intermediate trees is remarkably fast, in as few as 20 years. This approach is also useful in even-aged stands containing both fast and slow growing species, such as mixed pine—intolerant hardwood—tolerant softwood types. The tall intolerant species can be removed first in successive heavy cuttings, thus releasing the shorter tolerants and permitting development of regeneration of both tolerant and intolerant species (Hawley and Smith 1954).

APPLICATIONS—RED PINE

An excellent example of intensive practices employing the shelterwood technique in red pine is provided by Eyre and Zehngraff (1948) for stands in Minnesota. It involves at first low thinnings and improvement cuttings beginning at 40 years and repeated at 5 to 10 year intervals to 80 years, leaving about 270 trees per acre; then preparatory cuttings in which mainly codominants suitable for poles are removed, favouring dominants; following this at 120 years a seed cutting which reduces the crop trees from 120 to 50 trees per acre; another reduction of half the overwood at 130 years, releasing the established reproduction; finally, at 140 years the removal cut, provided regeneration is adequate—if not, planting or disking during the midsummer of a good seed year.

MODIFICATIONS—RED PINE

Where such intensive silviculture is not applicable, a *two-cut shelterwood* method is recommended (Zon 1912, Eyre and Zehngraff 1948), removing half the volume at 65 to 70 years and the remainder within 20 years when reproduction is well established. The interval should be less than 7 years according to Woolsey and Chapman (1914) if suppression of the seedlings is to be avoided, but it is quite possible that insufficient seed will have fallen in that time. Scarification during a seed year would again be helpful, particularly if brush is present (Eyre and Zehngraff 1948).

In mixtures of red and jack pine in the Lake States and adjoining Manitoba it is suggested that all of the jack pine be cut in the first shelterwood operation along with the coarser red pine, thus favouring red pine reproduction (Eyre and Lebarron 1944, Cayford 1956). The object should be to obtain by 70 years a red

pine stand with a basal area between 50 and 80 square feet per acre, a level which is best for the establishment of red pine seedlings, according to Ralston (1950).

There are no cases reported in Ontario of successful regeneration of red pine through shelterwood cutting of any type.

GENERALITIES

The case for shelterwood cutting in pine is fairly clear. It is best suited for intensive management in white pine, for situations where high yield would justify the high cost required in its application. It can be used in extensive forestry but alternatives are usually more economically effective.

Protection is the feature best characterizing the method—protection of the site and of the stand quality, protection against inedaquate stocking and against heavy losses through weather effects or, in white pine, weevilling. The disadvantages are mainly economic issues such as the unmerchantability of the small material which must be removed, and high logging and administrative costs. Unskilled or incorrect application of the method can, by necessitating additional cultural measures such as brush control, increase these costs appreciably. Thus careful study of the conditions is essential for its practice.

Selection Method

CHARACTERISTICS

The single-tree selection method of cutting is generally incompatible with pine. It aims at a balanced, uneven-aged stand, a condition which the degree of intolerance of both pines, and particularly red pine, resists. Even so-called virgin stands of white pine are generally even-aged. It would require a length of time equivalent to a whole rotation, with regular short reproduction periods for an originally even-aged stand to become a balanced, uneven-aged stand, and some irregularities would likely be introduced through damage (Hawley and Smith 1954). In any case, the costs of such a conversion would normally preclude it.

Selection cutting should not be confused with "selective cutting" which is an ambiguous term commonly applied euphemistically to haphazard hi-grading of pine stands. The result resembles an irregular shelterwood cut rather than a true selection cut (Hawley and Smith 1954, Place 1953).

APPLICATIONS

Despite the above generalizations there are limited instances where selection cutting is applicable to pine. Probably the most important is in parks and reserves. Woolsey and Chapman (1914) suggested the possibility of cutting red pine in irregular selected groups of 2 to 10 trees where mature stands are to be maintained for aesthetic or protective purposes. Larsson (1946) recommended "periodic selective logging" during seed years to remove overmature, defective and suppressed trees in lakeshore reservations of mature red and white pine in Ontario.

Certain commercial white pine conditions are also conducive to the selection method. Group selection cutting has been recommended for stands of old-field pine on sandy and gravelly soils, which are usually uneven-aged and grouped more or less naturally (Lutz and Cline 1947). The group opening should be kept small—50 or 75 feet across at most—to avoid adverse ground vegetation buildup. Thus this overlaps the group shelterwood method. A similar approach was

suggested by Sowers *et al.* (1956) for white pine in patchy mixed stands of the Alleghenies, combined with scarification, if needed. The selection method has been used in small areas of white pine in New England with fair results, but relatively poor density and growing conditions prevailed in the reproduction and, above all, the cost was found prohibitive.

Integrated Practices

The foregoing has made it abundantly evident that methods must be varied and adapted to suit first the economic circumstances and second the species and stand structure. Little has been said about adapting to site variations, and only recently has there been any emphasis on this aspect. Formerly generalized methods were rigidly adhered to over a great range of site and hence stand conditions. Extensive diameter-limit cutting in Canada (Maissurow 1935) and seed-tree cutting to 5 per cent of the original volume in the Lake States (Zon 1912, Eyre and Zehngraff 1948) fall in this category. Such methods, which frequently left inadequate, inferior seed sources, served often to forestall pine reproduction by encouraging competing vegetation.

Now it is clear that certain methods are particularly adapted to certain sites, that there are some sites where almost any method will provide adequate pine regeneration, and others where none will work. It is not usually site in itself but rather the effect of site on competing vegetation which brings about these differences.

In general, other factors aside, the drier the site, the lesser the competition and the greater the chance of pine reproduction regardless of cutting method. This is made evident in three references, Lutz and Cline (1947), Scott (1958), and McCormack (1959). McCormack presents detailed silvicultural proposals (see Table 9) for the central Canadian pine range, using landform as the primary site variable reflecting broad differences in soil texture, nutrients and moisture. His secondary variable is aspect-position. Generally, he recommends variable seed tree cutting with ground scarification where competition necessitates it. The main exceptions are the richer, finer soils of moulded till and lacustrine origin on which competition is so severe that pine management is not advocated. On sandy soils of glacio-fluvial origin, patch or strip cutting as well as seed tree cutting are usable.

Scott (1958) divides the pine sites in the Algonquin Park area of Ontario in a manner similar to McCormack's, but he emphasizes the shelterwood method as being most applicable in that locality. On the coarser, drier drift materials of the valleys, patch, seed tree or shelterwood cutting methods will, according to Scott, all reproduce white pine. Of the common associated species on those sites, aspen, white birch, red and jack pine will not reproduce well after logging, and spruce and fir are not aggressive, so that additional treatment is minimized. Silviculture must be more intensive and less flexible on the shallow till sites of the hills. There the shelterwood method is considered best for existing pine stands, permitting control of the vigorous competitors, aspen, birch, spruce and fir, and providing ample seed for white pine reproduction. Subsequent cleanings and improvement cuttings will be required. Prescribed burning may also be useful on this site. On deep tills (comparable to McCormack's moulded tills) it is possible to maintain "small islands of white pine in a sea of tolerant species", but

Table 9.—Harvest Methods for Red and White Pine

Landform	Dumped Till			Washed Till			Moulded Till			Glaciofluvial	Lacustrine
Aspect-Position	N	S	R	N	S	R	N	S	R	All	All
Recommendation	R	R	R	R	R	R	NR	NR	R	R	NR
Competition	S *CC	M CC	W	M CC	W	W	VS	VS	S	W ST	VS
Harvest method	ST	ST	CC	ST	ST	ST			CC	CC. patches, strips	
Scarification	Yes	Yes		Yes					Yes		
No. trees to leave	5–15	5–15	5	5–15	20–30	20–30				20–30	

KEY

Aspect Position

N — North slope

S — South slope

R — Ridge top

Recommendation

R — Treatment for regeneration recommended

NR — Treatment for regeneration not recommended

Competition

VS — very severe

S — severe

M — moderate
W — weak

Harvest Method

*CC. clear cut
ST. seed tree

*Note—For purposes of this table the term "clear cut" means cutting all trees except the number necessary for seed supply in case of subsequent fire—believed to be about 5 per acre.

only at great effort. Intensive uniform shelterwood or group cuttings together with seedbed preparation would secure pine reproduction but frequent cleanings would be needed to ensure its survival.

Thus if some silvicultural practices applicable on the poorer land types are attempted on the richer tills failure may result, whereas if the reverse were done, costs would be unnecessarily high. It is economically and silviculturally important to match the method to the ecological condition.

STAND GROWTH AND YIELD

Introduction

The genetical, physiological, ecological and cultural influences on the growth of pine have been dealt with. It remains to consider the mensurational aspects of growth on a stand basis, leading to growth and yield prediction which are essential for forest management.

The bulk of this chapter is taken from an empirical yield study made by McCormack in natural red and white pine stands of Ontario and adjoining Quebec, published for limited distribution by the Forestry Branch in 1956. All of the graphical data presented comes from this publication.

Red and white pine stands in this region today range from pure overmature stands through mixed, natural second-growth types to plantations. Density, site quality and actual composition vary widely, but the significant characteristics are a predominance of one or both pine species and an essentially even-aged overstorey structure.

McCormack's study attempts to provide a framework from which the growth and yield of any pine stand can be calculated with a minimum of details. His sample was extensive enough—involving more than 500 one-fifth-acre plots plus some stem analyses and remeasurement data—to be reliable for the region.

Height Growth

site relationships

Stands sampled by McCormack show a range in their dominant height/age relationship which falls naturally into four groups, representing good, moderate, poor and very poor sites as judged by soil moisture and parent soil material (refer to "Synecology"). These are shown in Figures 38 and 39. The group curves are not arithmetically arranged in the usual manner of site index curves; their actual level is not specific and they should be used only as guide lines, although there is an ecological basis for their shape and relative position. In very general terms Group I consists of the fresh and moist sites, Group II the somewhat dry, Group III the dry, and Group IV the very dry.

Other comparable investigations of red pine growth, those of Eyre and Zehngraff (1948) in Minnesota, and Ardenne (1950) in Ontario, show reasonably similar site relationships, allowing for the fact that they involve only three site classes. This is not the case with white pine. Gevorkiantz and Zon (1930) in Wisconsin and Frothingham (1914) in New Hampshire record much better growth than either McCormack or Ardenne in Ontario. This may be due to the fact that many of the stands sampled in the Northern States developed on abandoned agricultural land, under conditions for fast growth. Differences in sampling intensity and mensuration technique would also account for variation.

AGE RELATIONSHIP IN NATURAL STANDS

Curves of dominant height over age at breast height for each species are presented for each of the four site groups in Figures 38 and 39. Only dominants from stands containing 75 per cent by basal area red and white pine, pure or mixed together, were used. Age at breast height is used in preference to stump or total age in order to minimize the individual variation in growth which results from competition apart from site. In natural stands an average of 10 years is required for seedlings to reach breast height. This figure concurs with the findings of Gevorkiantz and Zon (1930), and Frothingham (1914) on white pine, and of Smithers (1954) on both white and red pine. Woolsey and Chapman (1914) found the period for red pine to be about 8 years.

Comparing the two species, it is evident that red pine grows faster than white at first. Then at an age which varies with site from about 40 to 85 years, as shown by the dotted line in Figure 38, the dominant white pines surpass the red and thereafter maintain a slight superiority. The better the site, the earlier this trend occurs. There is fairly general agreement on this point (Woolsey and Chapman 1914, Smithers 1954).

HEIGHT GROWTH IN PLANTATIONS

Planted stock has an advantage over natural reproduction because of less competition and a more vigorous structure, developed through transplanting. Curves of dominant height over age since planting for red pine plantations on three site groups are shown in Figure 40, together with individual tree growth as determined by selective stem analysis. Site group IV comprised of the poorest, driest conditions is not represented because of insufficient sample. Most white pine plantations had been damaged by weevil or blister rust or both, so comparable curves are not available for that species; as mentioned before, however, the initial height growth of white pine is generally somewhat slower than that of red.

The early superiority of height growth in plantations is evident from a comparison of Figures 38 and 40. While it takes an average of 10 years for natural-grown trees to reach breast height, planted trees require only 4 or 5, 6, or 7 years for site groups I, II and III respectively.

HEIGHT GROWTH IN MIXEDWOOD STANDS

The height-age relationship of pine in mixedwood stands is difficult to predict, varying as it does with relative species composition, density and age.

In immature stands the pine is generally suppressed to some extent by the faster growing hardwood species. But there is evidence that suppressed trees, when released, will grow at a faster rate than comparable unsuppressed specimens of the same height. In Figure 41 the height growth trends of selected white pines which had been variously suppressed for a period by other species are shown along with the dominant height curve appropriate for the site involved. Tree number 1 was partly suppressed for 50 years, then grew at an accelerated rate until, at 150 years, it reached the general height of the free-growing dominants. Tree number 3, on the other hand, suffered greater, longer suppression, and remained in a subordinate position. The physiological basis for these tendencies has not been explained. Whatever the reason, it is evident that early release of pine in mixedwood stands is essential if maximum growth at a reasonable rotation age is the aim.

81968-0—8

Figure 38

HEIGHT - AGE BY SITE

RED PINE NATURAL STANDS

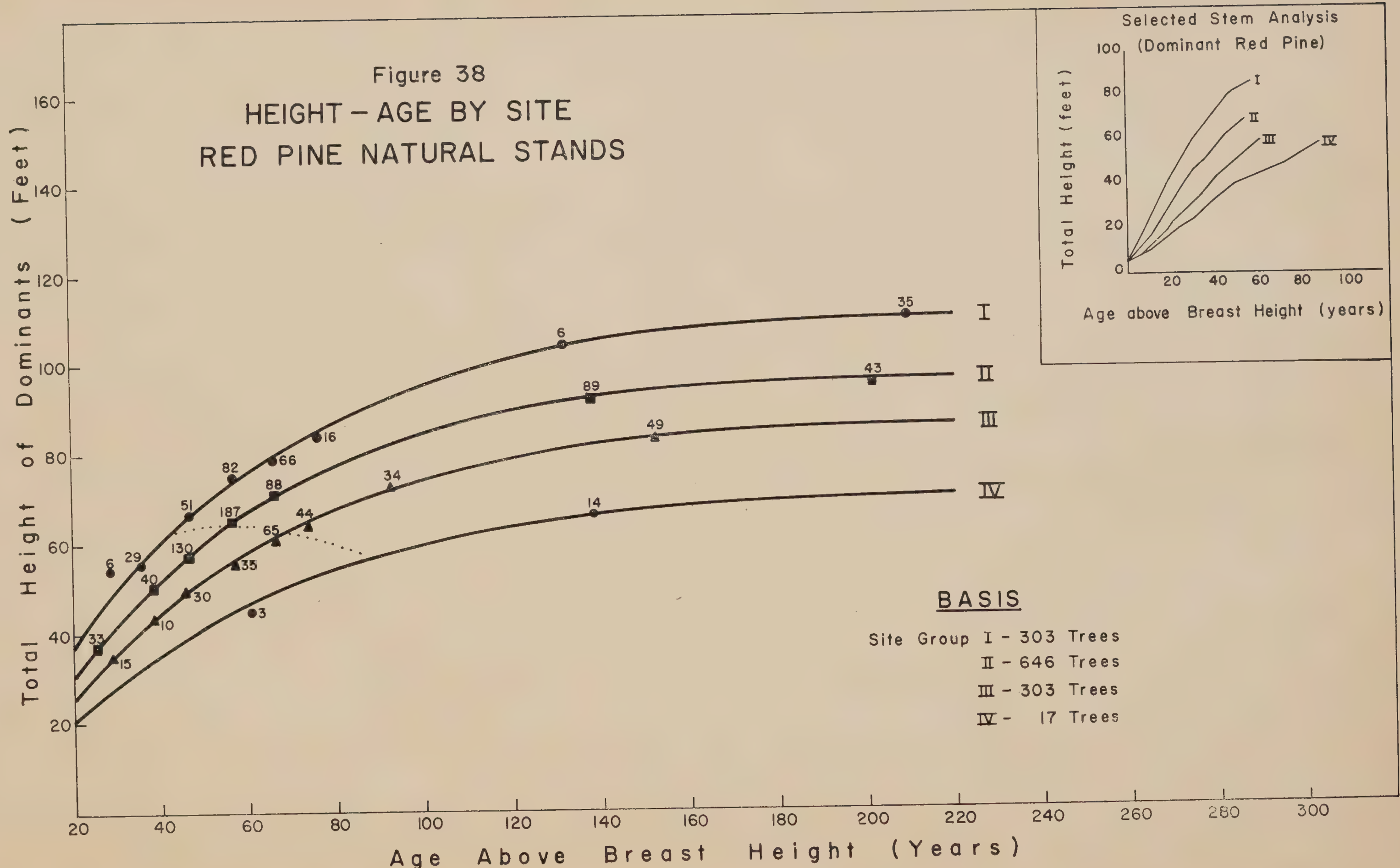
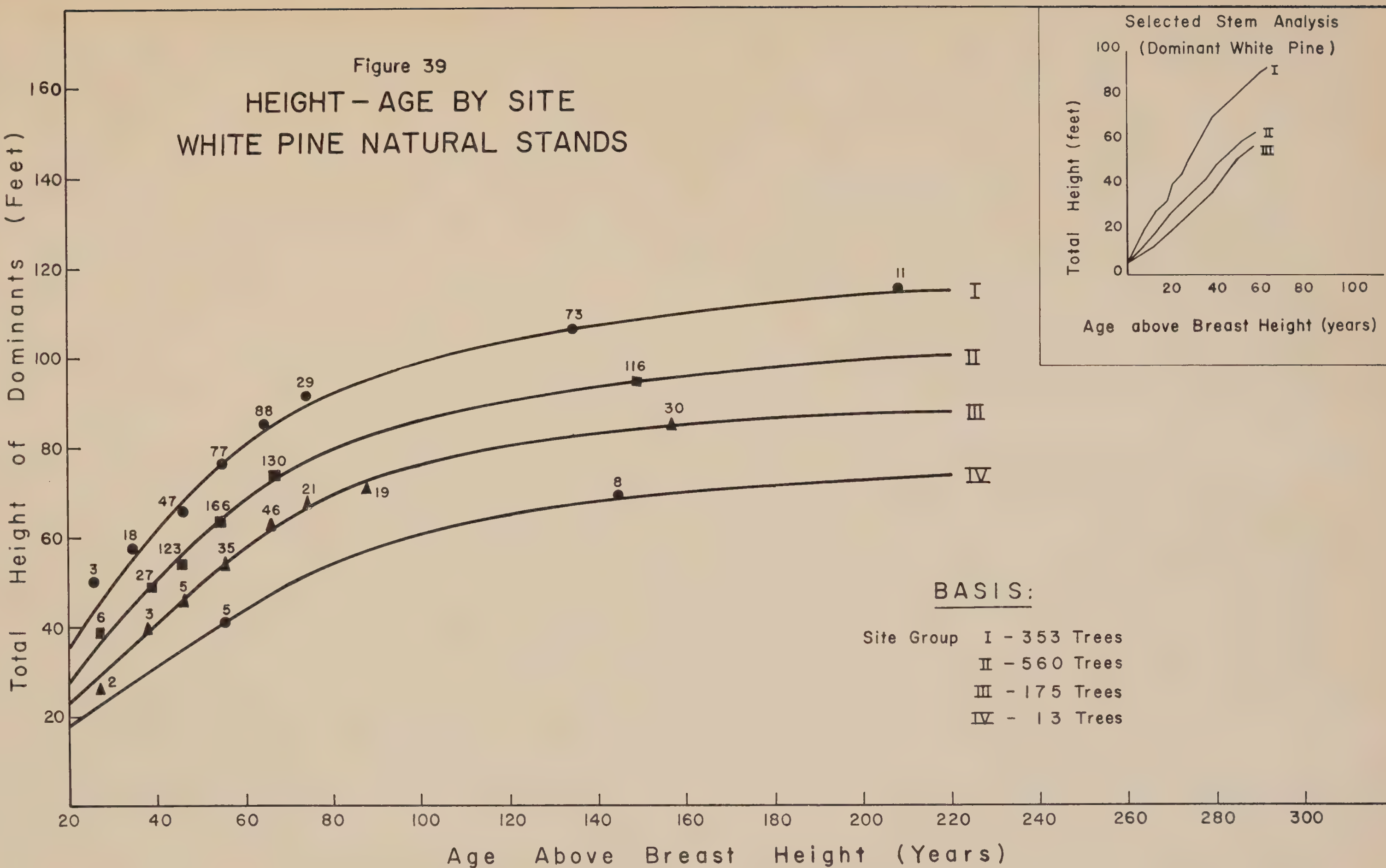


Figure 39

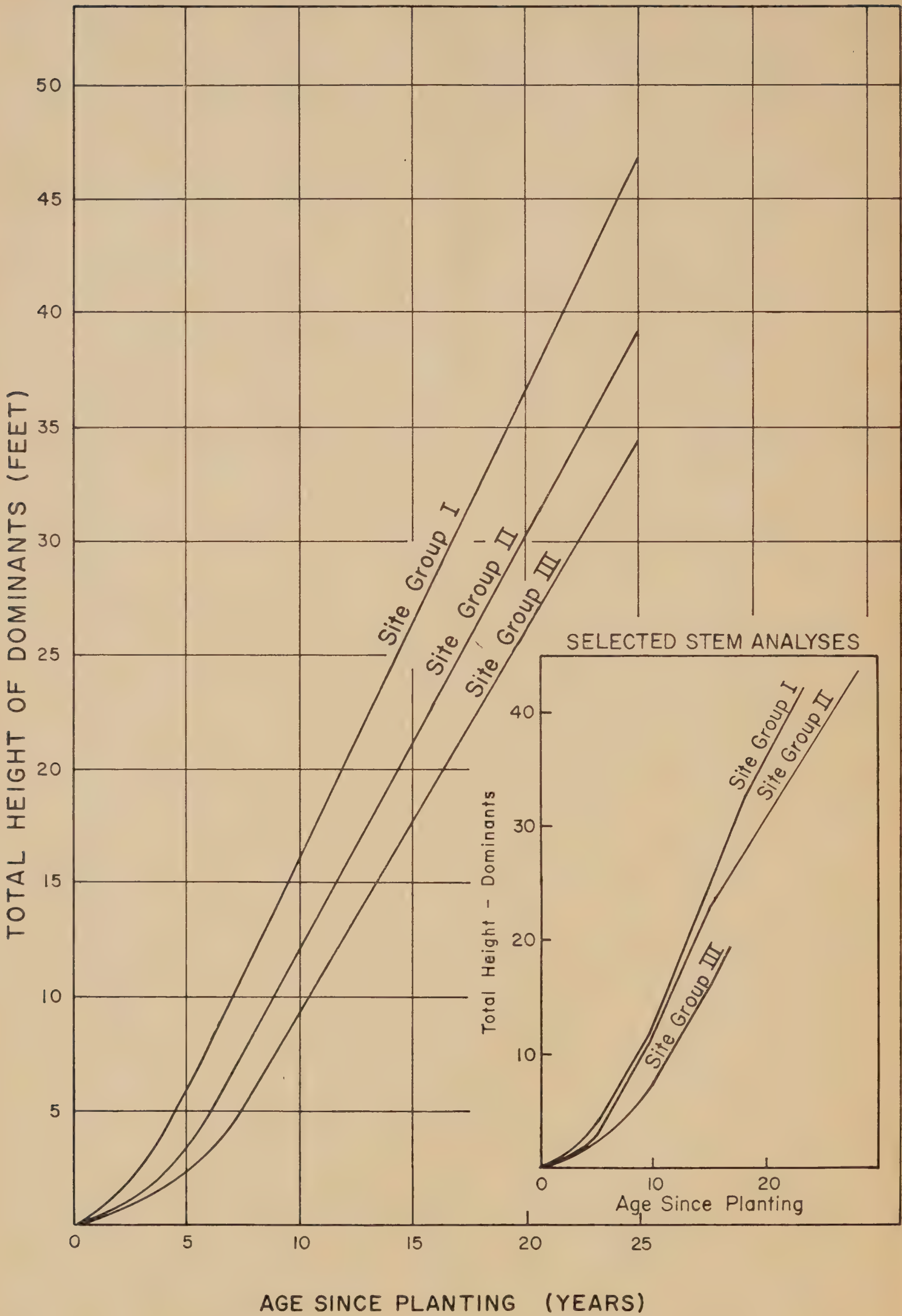
HEIGHT – AGE BY SITE
WHITE PINE NATURAL STANDS



81968-0—8½

FIGURE 40

HEIGHT GROWTH IN RED PINE PLANTATIONS



DOMINANT VS. AVERAGE HEIGHT

Dominant height, of course, involves only trees with crowns above the general canopy level. Average height includes trees of all crown classes approximately in the proportion that they occur. The correlation of the two as found in McCormack's sample of pine stands is shown in Figure 42. Although this relationship will vary with site and density, the average trend is consistent and hence useful for inventory purposes. The shape of the curve and its position is influenced by the fairly rapid initial height growth of dominants, which later slows down. Average height tends to increase at a fairly uniform rate until, at older ages when the more suppressed trees die off, it approaches the value for dominant height.

Diameter Growth

Studies have indicated that density has a marked influence on diameter growth, which confounds the effect of site. Smithers (1954), dealing with red and white pine, states that "although the effect of site quality on diameter growth is much less marked than that of density, site does influence the pattern of stem diameter distribution, which is of considerable importance in developing thinning regimes". Stand density also influences diameter distribution—the lower the density, the higher the proportion of dominants (Rudolf 1957).

Diameter-age curves for natural pine stands in three site groups are presented in Figure 43. They are based on average diameter of the 50 largest red and white pine trees per acre, a method of analysis which to some extent separates the effects of density and site. These values thus represent the best diameter growth than can, on the average, be expected in the natural stands of Ontario. Considerable stand improvement would be required to bring most existing stands, with their proportion of poor-quality trees, up to this standard. Intensive stand management in which proper distribution and optimum densities are maintained would, on the other hand, probably yield higher average diameters than the curves give. Heiberg (1953), for instance, states that it is possible to maintain a diameter increment of one inch for every 3 or 4 years on dominant trees, and every 4 to 6 years on the average trees.

The tendency in the curves of site groups II and III to droop beyond age 160 is not particularly significant. It may result from inadequate sampling; it could also be caused by blowdown amongst the larger trees under those conditions, which would automatically reduce the stand average.

Stand Stocking

DENSITY

Stand stocking is influenced by a number of factors of stand history which, though they do not lend themselves to mensuration, can be minimized by selective sampling. In this case only pine stands of fire origin, predominantly pure and even-aged, are considered.

Stocking is also influenced by site, as shown in Figure 44. To clarify this relationship only trees of the main age-class have been used. Saplings, usually balsam fir, spruce, aspen or birch, which are often present as a younger understorey, particularly in lightly stocked and older stands, have been omitted; they are relatively ineffectual as competitors in any case.

FIGURE 41-STEM ANALYSES OF WHITE PINE ORIGINATING IN MIXED-WOOD CONDITION

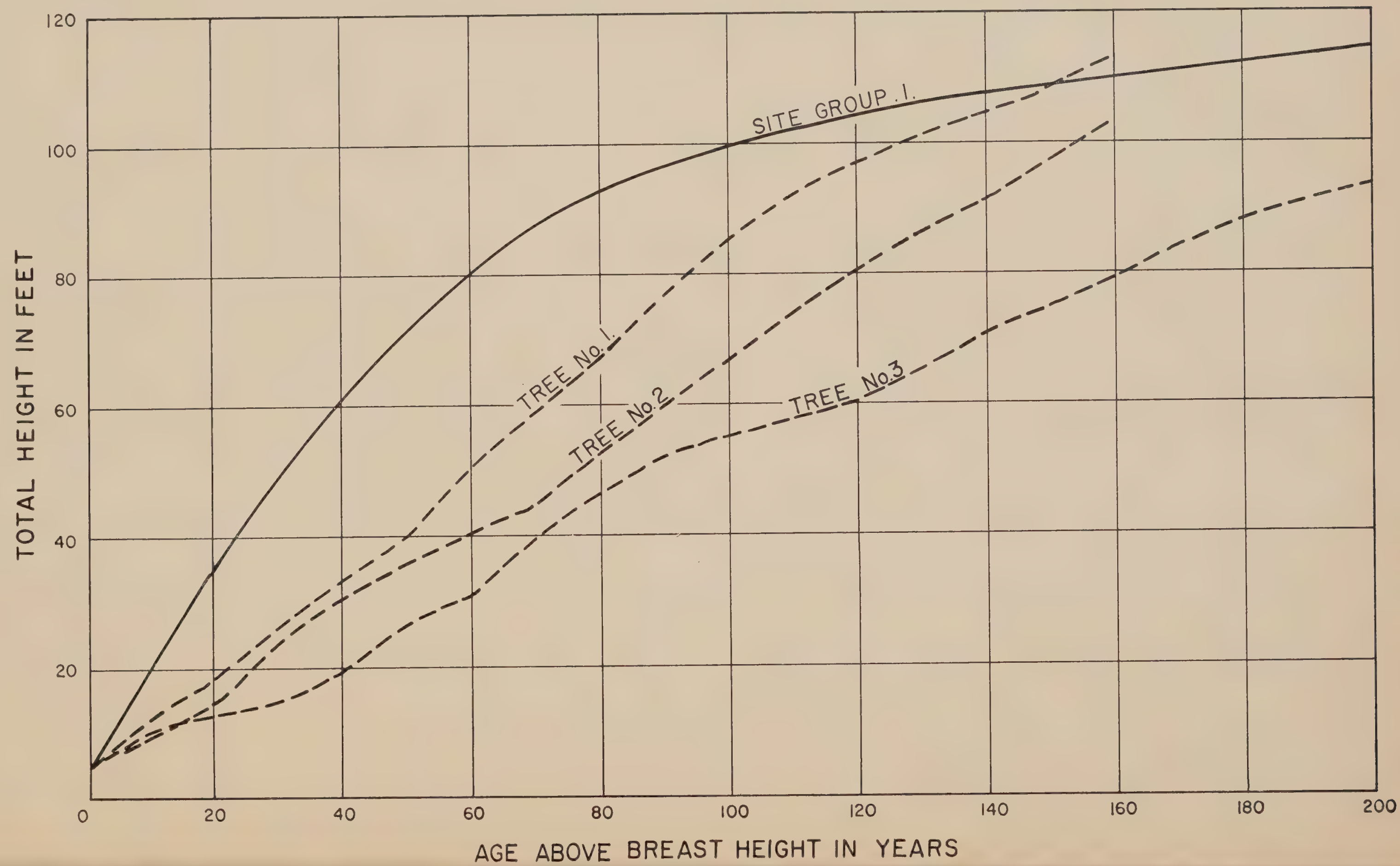


FIGURE 42-CORRELATION DIAGRAM
AVERAGE-AND DOMINANT HEIGHTS

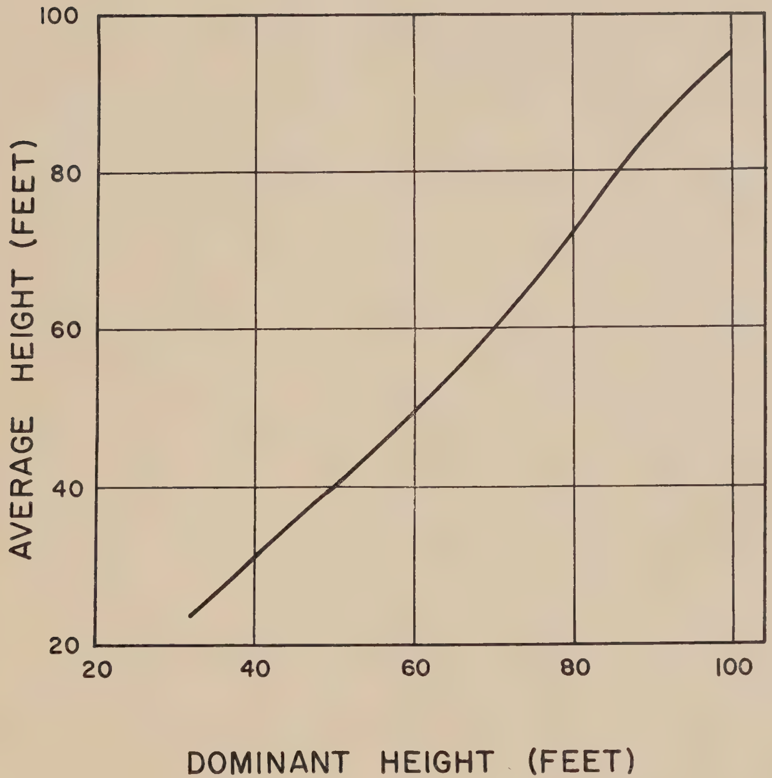
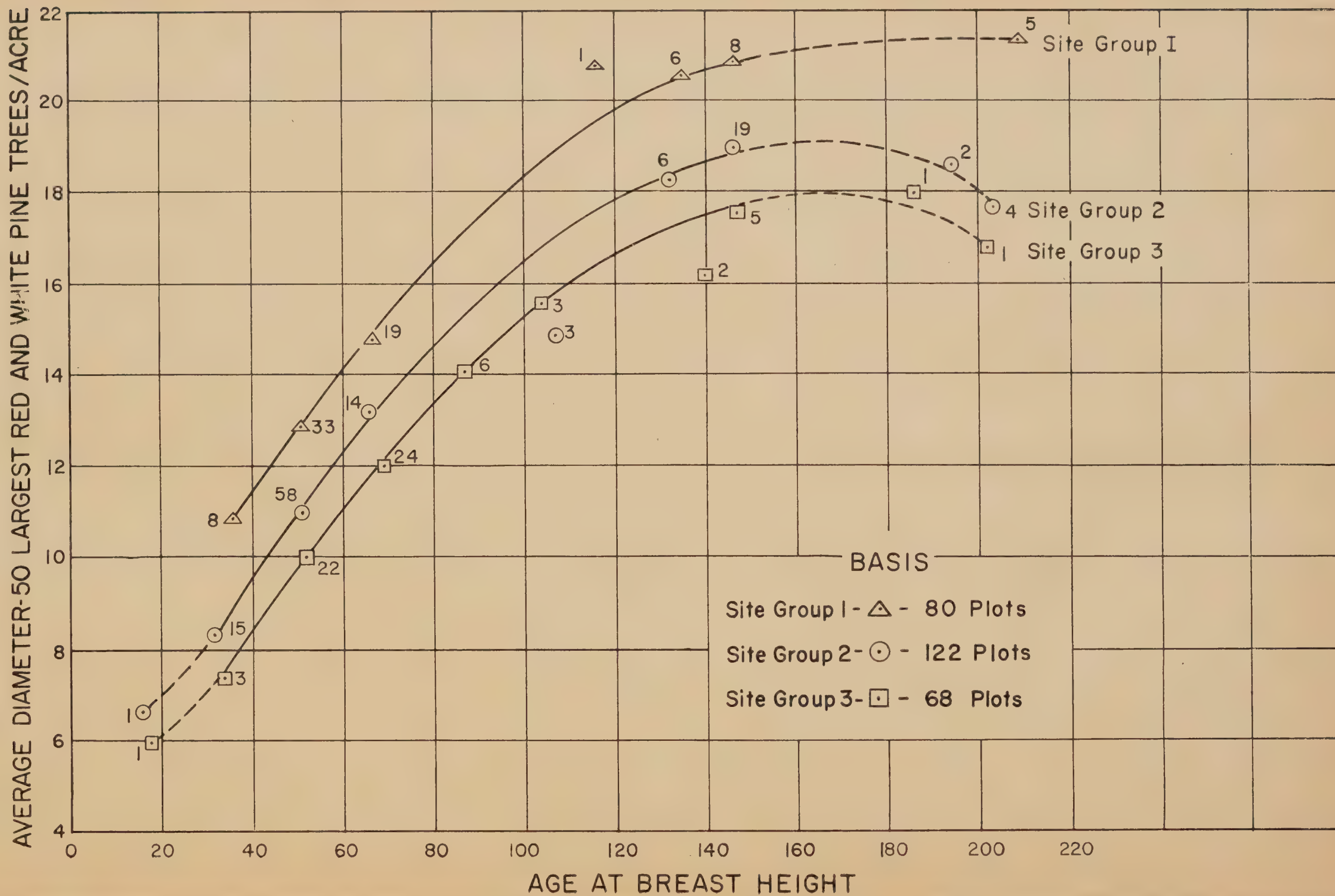


FIGURE 43-DIAMETER OF 50 LARGEST RED AND WHITE PINE PER ACRE



As would be expected, there is a wide variation in number of trees per acre at any given age, as shown by the curves representing upper and lower limits in Figure 44. On all sites there is an abrupt decrease in numbers to about 450 trees per acre, and a gradual decline thereafter. All sites tend to support a similar number of trees, particularly towards maturity.

BASAL AREA

In a normal rotation period stands which are initially of low density will tend to approach the basal area of fully-stocked stands. However, considerable variation in basal area exists between different sites, as illustrated in Figure 45, by average basal area trends for four site groups. On the better sites diameter growth is more rapid and fewer trees are suppressed, so that higher basal areas prevail.

McCormack's trends are generally similar, indicating rapid growth in basal area for the first 30 to 50 years, varying with site, followed by a slow, steady increase.

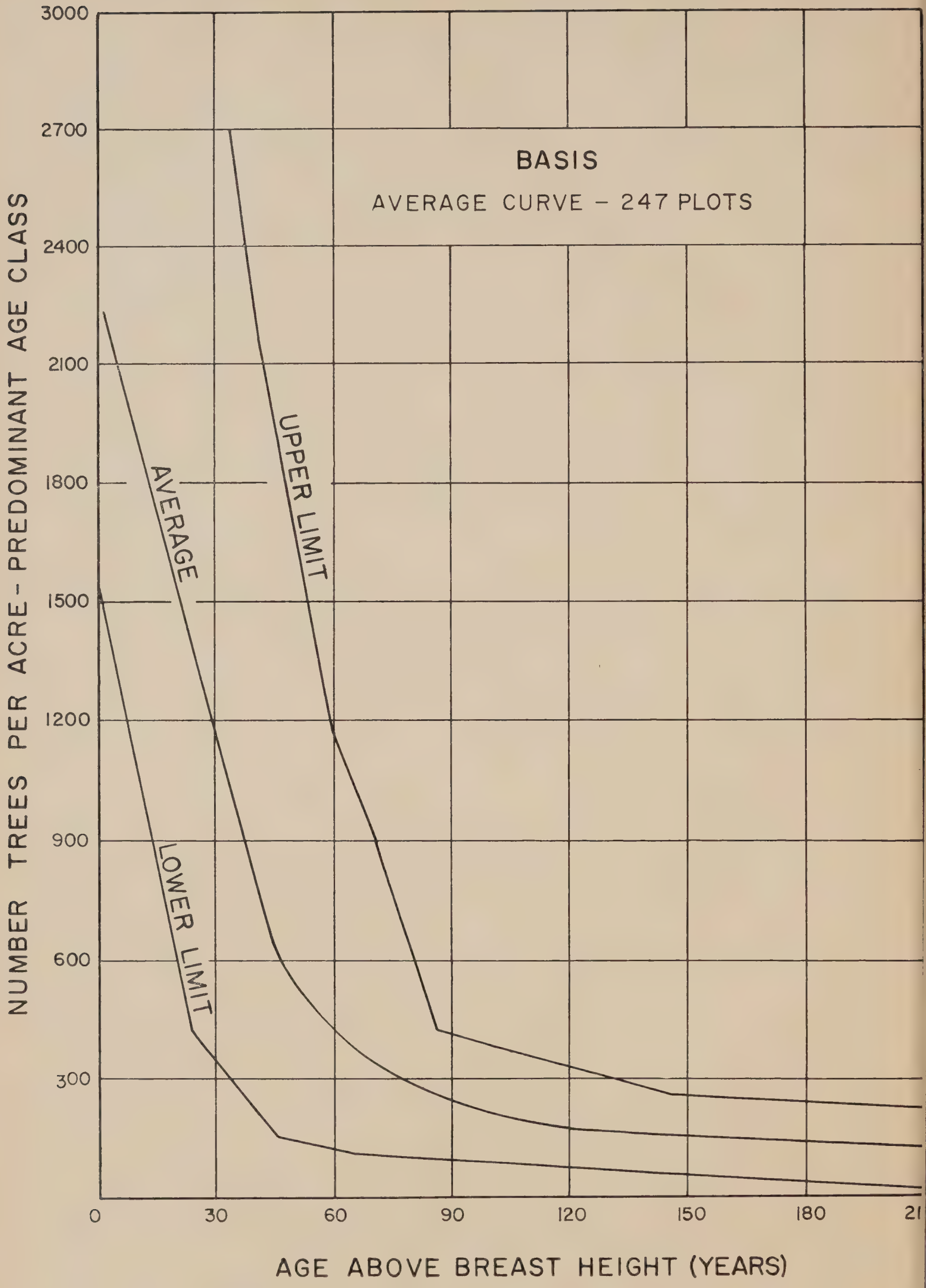
Many of the stands sampled for Figure 45 tended to be understocked and mortality was relatively low. In well-stocked or over-stocked stands mortality may equal or for short periods even exceed growth, in which case the net current annual increment would be small or even negative. From such stands of red and white pine at Petawawa, Smithers (1954) concluded that, "in general the maximum basal area in pine stands seems to be reached at approximately 55 years of age and this value is related to site quality". "Thereafter", he states, "basal area increment is balanced by mortality so that the net stand basal area remains relatively constant at ages greater than 60 years". For well-stocked, unmanaged stands of red pine in Minnesota, Eyre and Zehngraff (1948) found a small increase of basal area with age up to 160 years on all sites, and showed a separation by sites, although of less magnitude than found by McCormack. Similarly, Gevorkiantz and Zon (1930) in Wisconsin, and Tarbox (1924) in Massachusetts found an increase of basal area with age and a separation by site, although their actual values are considerably higher. Thus it appears that in all but very well-stocked or over-stocked stands, which are a minor part of the existing pine forest in Ontario and Quebec, there is a tendency for basal area to increase slightly with age, until the stands actually start to break up.

In plantations the growth pattern appears to be similar to that in natural stands. The main differences, resulting from initial advantages in growth and better distribution, are that basal areas are virtually always higher, that the point at which rapid growth in basal area abruptly slows down is reached earlier—at 20 to 30 years usually—and that stands will, unless thinned, become overstocked so that net basal area increment diminishes. Allison and Cole (1956) found that it ceases when a level of about 250 square feet per acre is reached in older red pine plantations.

VOLUME

The conventional method of determining volumes for even-aged coniferous stands in Ontario is through height-diameter curves and standard form-class volume tables (Bedell 1948, Anon. 1948, Anon. 1953). There is however, a short-cut method, presented by McCormack, which compares favourably yet requires a minimum of stand information—only average height, average diameter and

FIGURE 44 - NUMBER OF TREES PER ACRE



basal area. Their relationship is shown in Figure 46, in which volume (total, merchantable cubic feet and board feet, Ontario Log Rule) per square foot of basal area is plotted over the height of the tree of average basal area. The result in every case is a shallow S-shaped curve.

To facilitate interpretation a table of values read from the curves of Figure 46 is presented below.

Table 10—Volume determination from Figure 46

Height of tree of average basal area	Volumes per square foot of basal area		
	Total cu. ft.	Merchantable cu. ft.	Merchantable bd. ft.
20	14.0	5.6	12
25	14.8	7.1	15
30	16.0	8.9	20
35	17.3	10.7	26
40	19.0	12.8	35
45	20.8	14.9	45
50	22.6	17.1	56
55	24.6	19.5	69
60	26.7	21.9	84
65	28.9	24.3	100
70	31.0	26.8	117
75	33.3	29.3	136
80	35.6	31.8	157
85	38.0	34.2	179
90	40.1	36.5	196
95	41.9	38.4	211
100	43.4	40.0	222
105	44.6	41.1	230
110	45.4	41.8	235

To find the per acre volume of any pine stand the procedure is as follows:—

(1) Determine tree of average diameter by basal area method.

(2) From measurements or height/diameter curves find the height of this tree.

(3) From appropriate curve of Figure 46 or from Table 10 find required volume (total or merchantable in cubic or board feet) per acre per square foot of basal area.

(4) Multiply this value by the average basal area of the stand to find the average stand volume per acre.

Bedell and Berry (1955), in using this concept with other species, pictured the relationship for merchantable volume in cubic feet as a straight line. They were dealing with values at the centre portion of the curve which, in Figure 46, do approximate a straight line. The level of the curve of merchantable cubic foot volume and that shown by Bedell and Berry for a number of other species are very similar. It seems that, regardless of species, the ratio of merchantable volume in cubic feet to basal area is remarkably similar. If dominant heights only are available, as in the case of aerial photographs used for inventory purposes, it is

FIGURE 45-BASAL AREA - AGE WHITE AND RED PINE

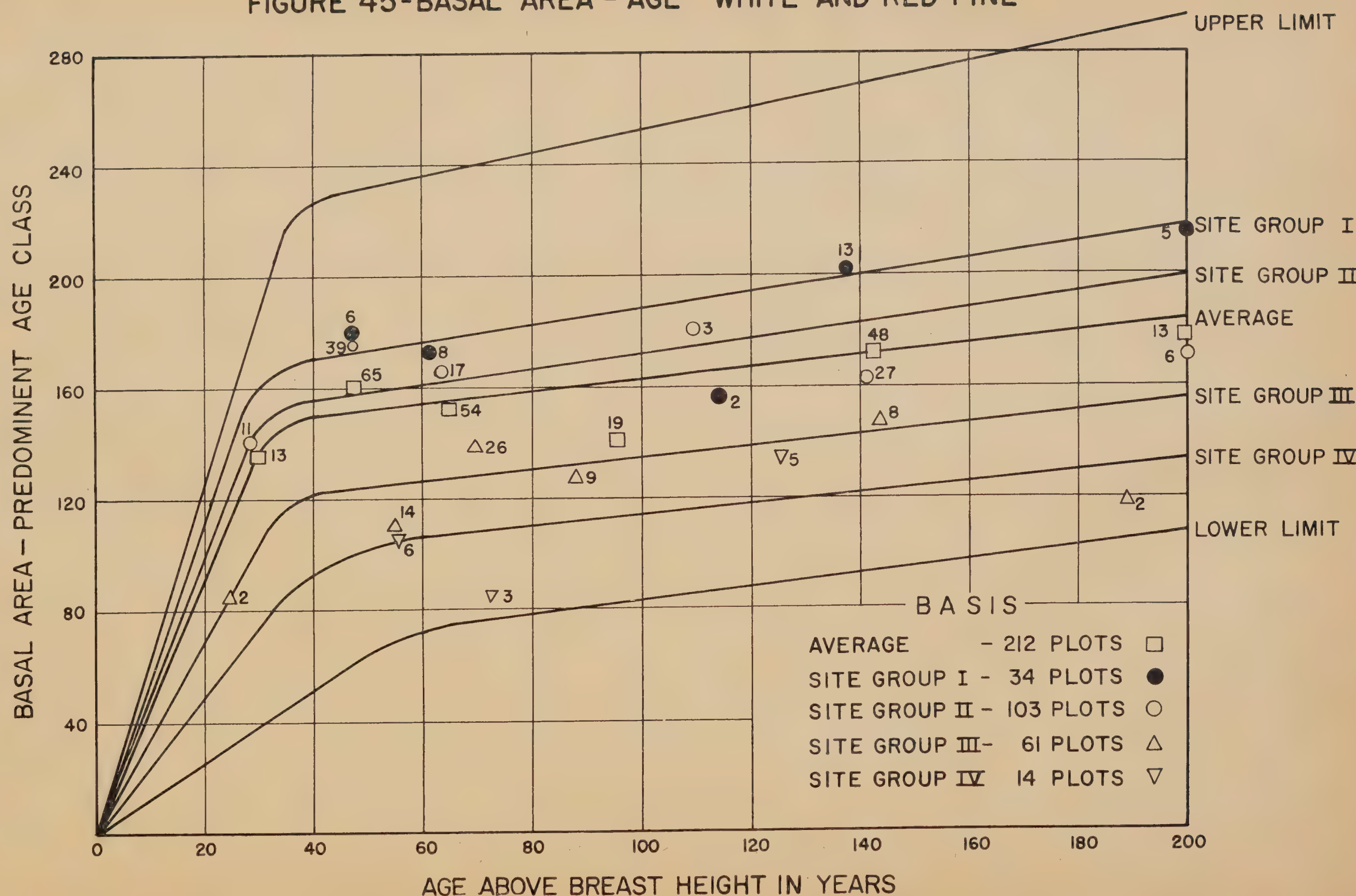
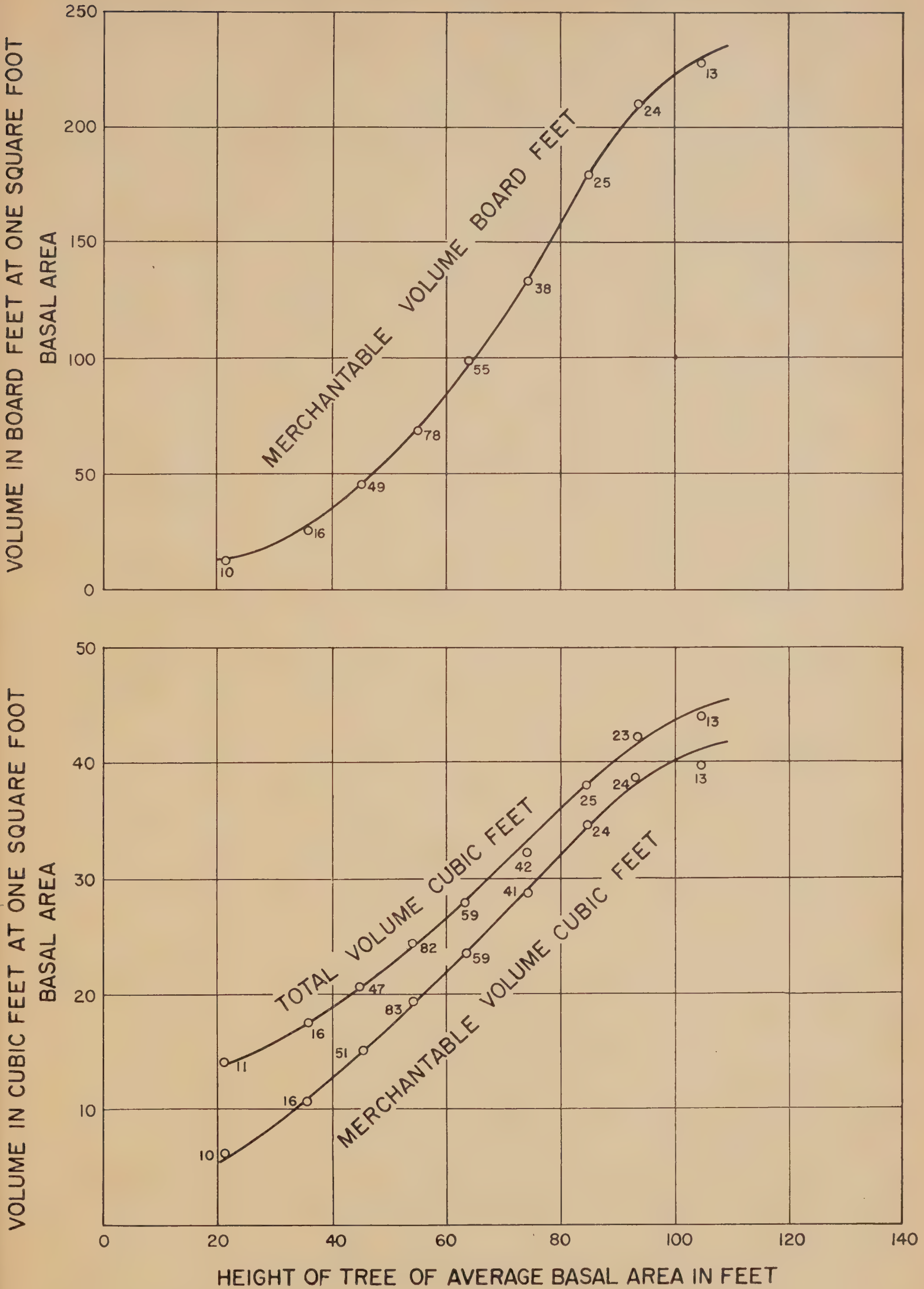


FIGURE 46 – VOLUME – WHITE AND RED PINE



also possible, by this method, to find an approximate stand volume. Dominant heights can be converted to average heights by the relationship in Figure 42, and this value can be used to obtain volume in Figure 46.

Stand Volume Prediction

From the curves in Figures 38, 39, 42, 44, 45 and 46, McCormack prepared yield tables (Table 11) for pine stands of average density occurring on the four site groups established in his study. For stands which vary from the average on these sites, the prediction of yields is based on the assumption that any existing differences will be proportionately maintained in the future.

As an example, a red and white pine stand occurring on a group II site is found at the age of 64 years to have a dominant height of 73 feet and a basal area of 168 square feet per acre. To calculate the present total cubic foot volume from the table, the unit volume per square foot of basal area is taken to vary directly as the dominant height. Thus by interpolation between the dominant heights of 68 and 78 in the table, the unit total cubic foot volume per square foot of basal area for the present stand is 28.0. The estimated volume per acre is 28.0 $\times$168 or 4,700 cubic feet. It should be noted that where the actual average height of the stand is known, it would replace the dominant height as the basis of estimation.

In predicting the yield of the stand at age 100 the difference in the predicted dominant height from the average (tabular) dominant height at that age is determined simply on a percentage basis. By interpolation the average dominant height at age 64 is found to be 70 feet but since the actual dominant height is 73 feet, the latter at age 100 should be $85\times\frac{73}{70}$ or 89 feet. By the same procedure the basal area of the stand at age 100 would be 178 square feet per acre. By interpolation the total cubic foot volume for a dominant height of 89 feet is found to be 37.4 cubic feet. Thus the predicted volume for the stand at age 100 is 37.4$\times$178 or approximately 6,700 cubic feet.

Straight-line interpolation is possible in these tables without reference to the original curves because for short intervals the curves closely approximate straight lines so that any differences between interpolated and curve values do not seriously affect the estimate.

The volumes of stands which have had intermediate treatments can be predicted in this manner providing they have been thinned lightly at fairly frequent intervals.

Another method, less accurate when tested, is to use the yields in Table 11 directly for prediction. For extensive areas dealt with by management plans, differences would tend to balance each other and the results of predictions could be expected to be within 15 per cent of actual volumes.

McCormack's merchantable cubic foot yields compare closely with those of Eyre and Zehngraff (1948) for natural red pine stands in Minnesota, interpolating from 4 sites to 3. Indeed, on this basis the yields at rotation age (140 years) are practically identical in the two studies. Moreover, as Rudolf (1957) states, rather comparable yields have been reported from other areas (Ross 1913, Reed 1926, Schantz-Hansen 1923, Spurr and Allison 1956). It must be noted, however, that these yields do not apply to the understocked pine and mixed stands which are so common in the natural forests of the region. Rudolf (1957) gives an example

FIGURE 47– CHANGE IN COMPOSITION

Mixed Red and White Pine Stands

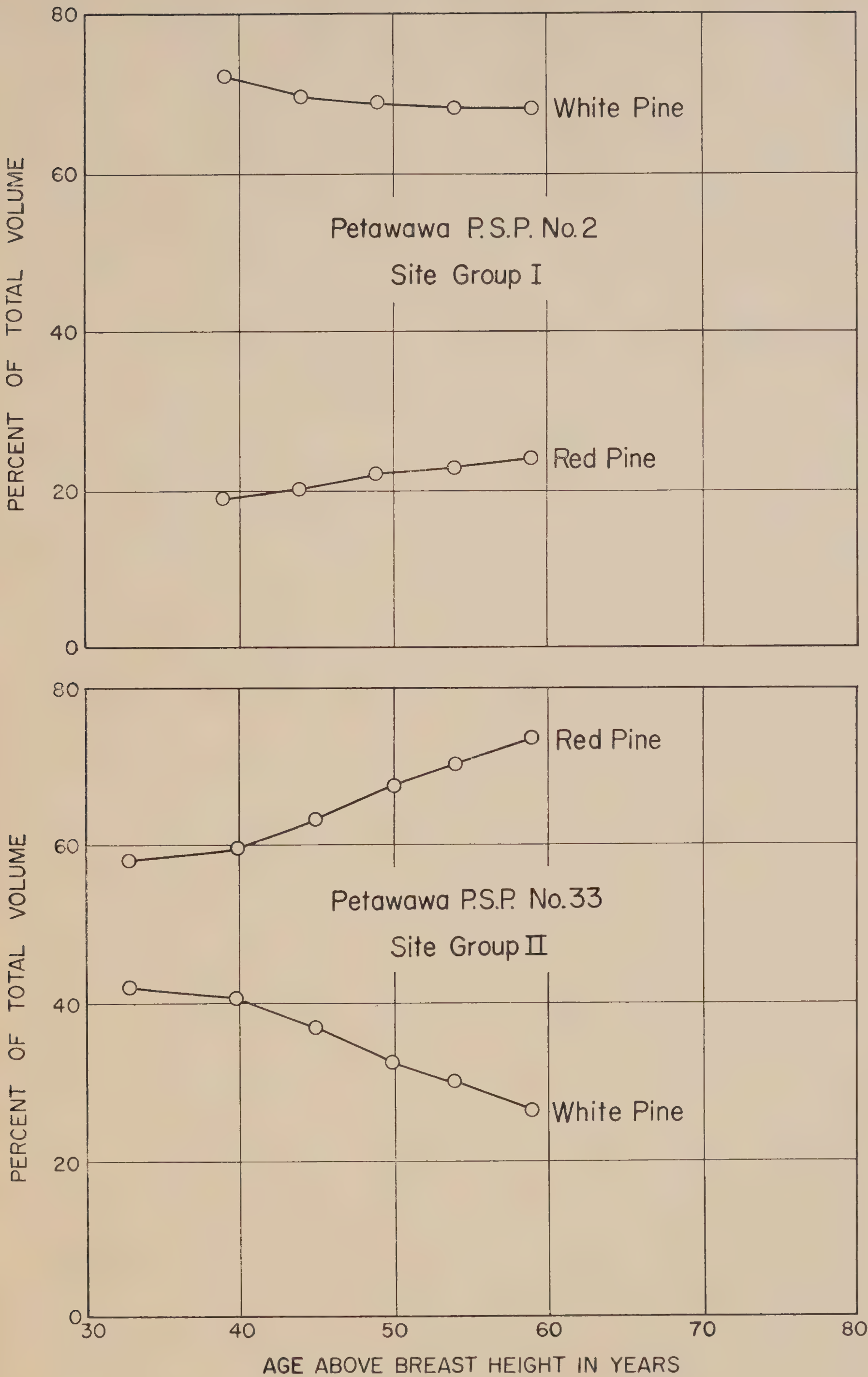


Table 11—Per Acre Yields of Stands of Average Density

Breast Height Age	Height		Unit Vol. per Sq. Ft. of B.A.				Average Volume			Increment					
										Total Cu. Ft.		Merch. Cu. Ft.		Merch. Bd. Ft.	
	Dominant	Average	Total Cu. Ft.	Merch. Cu. Ft.	Merch. Bd. Ft.	Av. B.A.	Total Cu. Ft.	Merch. Cu. Ft.	Merch. Bd. Ft. Ont. Log Rule	Periodic	Mean	Periodic	Mean	Periodic	Mean
	Figs. 38-39	Fig. 42	Fig. 45	Fig. 45	Fig. 45	Fig. 44									
Site Group I															
20	37	28	15.5	8.1	18	113	1,752	915	2,034		88		46		102
										104		100		374	
40	61	50	22.6	17.1	56	170	3,842	2,907	9,520		96		73		238
										85		95		589	
60	79	71	31.5	27.3	121	176	5,544	4,805	21,296		92		80		355
										69		71		564	
80	90	85	38.0	34.2	179	179	6,916	6,224	32,578		86		78		407
										42		42		298	
100	98	93	41.2	37.6	205	188	7,746	7,069	38,540		77		71		385
										25		26		158	
120	103	* 97	42.5	39.1	215	194	*8,245	*7,585	*41,710		69		63		348
										19		17		104	
140	106	* 99	43.1	39.6	219	200	*8,620	*7,920	*43,800		62		57		313
										16		16		97	
160	109	*100	43.4	40.0	222	206	*8,940	*8,240	*45,732		56		52		286
										16		14		77	
180	111	*101	43.7	40.2	223	212	*9,264	*8,522	*47,276		51		47		263
										15		14		78	
200	112	*102	43.9	40.4	224	218	*9,570	*8,807	*48,832		48		44		244
Site Group II															
20	30	* 22	14.2	6.2	13	99	*1,406	* 614	*1,287		70		31		64
										82		75		238	
40	52	42	19.7	13.6	39	155	3,054	2,108	6,045		76		53		151
										51		58		302	

60	68	57	25.3	20.3	75	161	4,073	3,268	12,075		68		54		201
										50		55		342	
80	78	69	30.6	26.3	114	166	5,080	4,366	18,924		64		55		237
										48		50		361	
100	85	79	35.1	31.2	152	172	6,037	5,366	26,144		60		54		261
										35		34		277	
120	90	85	38.0	34.2	179	177	6,726	6,053	31,683		56		50		264
										22		23		154	
140	93	88	39.2	35.6	190	183	7,174	6,515	34,770		51		47		248
										20		19		114	
160	95	90	40.1	36.5	196	189	7,579	6,899	37,044		47		43		232
										17		16		107	
180	97	92	40.8	37.2	202	194	7,915	7,217	39,188		44		40		218
										16		15		91	
200	98	93	41.2	37.6	205	200	8,240	7,520	41,000		41		38		205

Site Group III

20	25	—	—	—	—	69	—	—	—		—		—		—
										—		—		—	
40	43	33	16.8	9.9	24	121	2,033	1,198	2,904		51		30		73
										34		40		164	
60	58	47	21.5	15.8	49	126	2,709	1,991	6,174		45		33		103
										35		40		218	
80	69	59	26.2	21.4	81	130	3,406	2,782	10,530		43		35		132
										26		28		182	
100	75	66	29.1	24.8	105	135	3,929	3,348	14,175		39		33		142
										24		23		147	
120	80	72	31.9	27.6	124	138	4,402	3,809	17,112		37		32		143
										22		23		145	
140	83	76	33.8	29.8	140	143	4,833	4,261	20,020		34		30		143
										17		16		124	
160	85	79	35.2	31.2	153	147	5,174	4,586	22,491		32		29		141
										10		11		61	
180	86	80	35.6	31.8	157	151	5,376	4,802	23,707		30		27		132
										11		10		62	
200	87	81	36.1	32.3	161	155	5,595	5,006	24,955		28		25		125

*Note—Values approximate only—read from extensions of curve.

(cont'd)

Table 11 (continued)

Breast Height Age	Height		Unit Vol. per Sq. Ft. of B.A.			Av. B.A.	Average Volume			Increment					
										Total Cu. Ft.		Merch. Cu. Ft.		Merch. Bd. Ft.	
	Dominant	Average	Total Cu. Ft.	Merch. Cu. Ft.	Merch. Bd. Ft.	Av. B.A.	Total Cu. Ft.	Merch. Cu. Ft.	Merch. Bd.Ft. Ont. Log Rule	Periodic	Mean	Periodic	Mean	Periodic	Mean
	Figs.38-39	Fig. 42	Fig. 45	Fig. 45	Fig. 45	Fig. 44									
Site Group IV															
20	20	—	—	—	—	50	—	—	—	—	—	—	—	—	—
40	33	25	14.8	7.1	15	93	1,376	660	1,395	26	34	26	16	79	35
60	46	36	17.8	11.1	28	106	1,887	1,177	2,968	17	31	21	20	88	49
80	55	44	20.3	14.5	43	110	2,233	1,595	4,730	16	28	16	20	80	59
100	60	49	22.2	16.7	55	115	2,553	1,921	6,325	15	26	16	19	73	63
120	65	54	24.2	19.0	66	118	2,856	2,242	7,788	12	24	12	19	68	65
140	67	57	25.3	20.3	75	122	3,087	2,477	9,150	11	22	11	18	53	65
160	69	59	26.2	21.4	81	126	3,301	2,696	10,206	9	21	8	17	36	64
180	70	60	26.7	21.9	84	130	3,471	2,847	10,920	6	19	6	16	33	61
200	71	61	27.0	22.3	87	133	3,591	2,966	11,571		18		15		58

of over-all *average* yields of red pine at rotation age, applicable to the Lake States. For unmanaged stands they are less than one-third of the comparable yields calculated in Table 11, and for intensively managed stands, less than one-half. The average annual increment can apparently be doubled by intensive management.

Stand Composition Prediction

In addition to predicting stand volume it is useful to have some idea of future stand composition. Where the young stand is almost pure red or pure white pine there is no problem—it will ordinarily remain so during the full rotation. With mixed pine stands, however, utilization will vary with changes in relative specific composition.

It was pointed out earlier that red pine grows faster in height than white pine on similar sites at young ages. In site group I there is little difference but on drier sites the white pine is at a definite disadvantage. This differential height growth combined with the frequent depredations of weevil and blister rust on white pine means that red pine in mixed stands will usually increase in relative volume towards rotation age (at later ages natural succession would be towards white pine). This tendency is illustrated in Figure 47.

Yield Study Methods

Empirical yield tables are not adequate for some conditions. McCormack's table described herein is based on variously mixed red and white pine stands and is broadly applicable in the region as a whole. However, there are specific differences in the growth trends of the two pines, so that an error is incurred in applying the table to pure stands of either species. Normal yield tables are more acceptable for intensive management of stands of a single species, and studies are underway to prepare such tables for red and white pine respectively in Ontario.

Neither the empirical nor the normal yield study approach applies well to pine in the frequent mixedwood stand condition, but there is a method which may, with variation, apply—namely the "cofrequency method" conceived by Prof. T. W. Dwight of the University of Toronto and described by Smithers (1949). Further research in adapting this method, which is based on diameter growth comparisons taken over the full life of trees in a mature stand, is in progress.

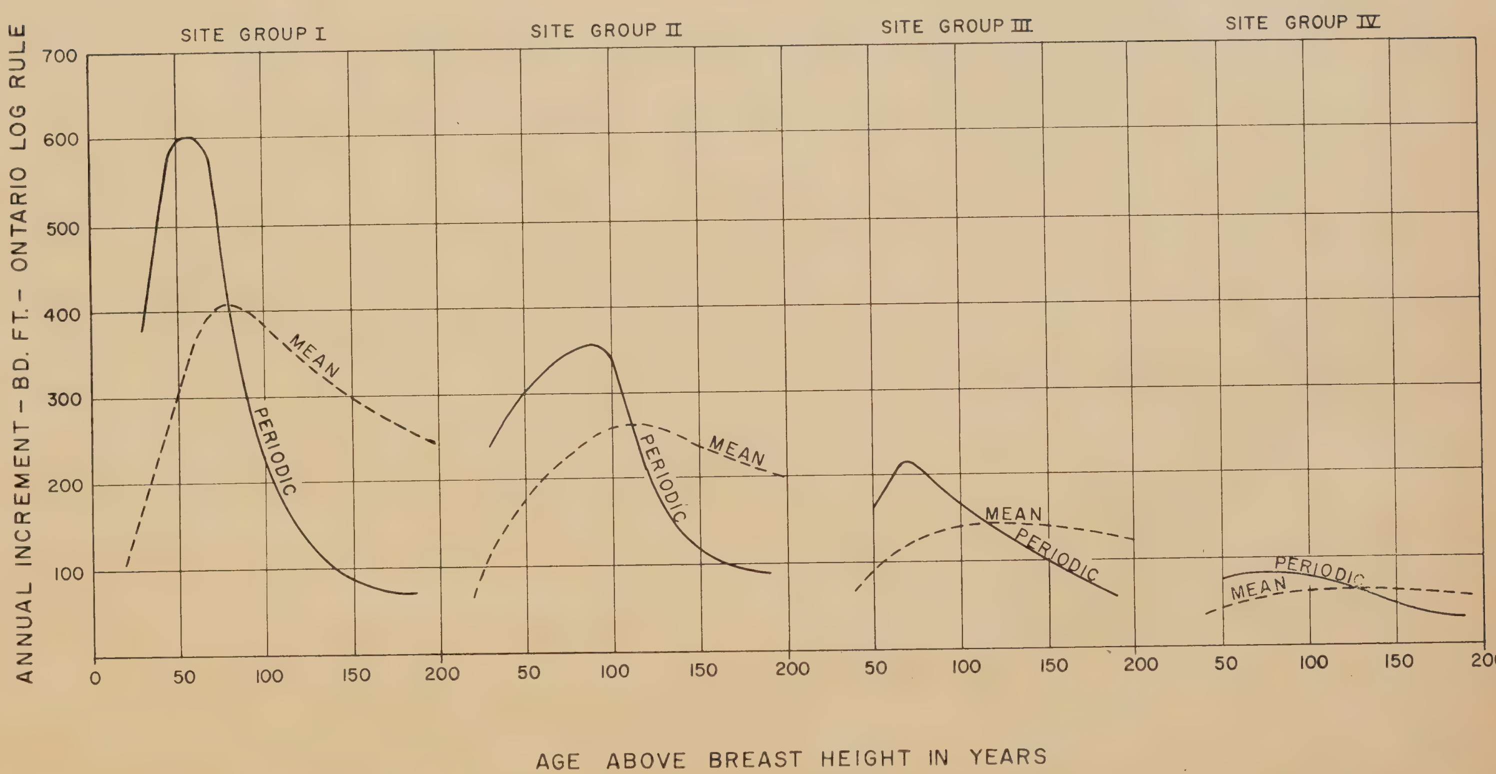
Rotation Age

There are many ways by which a rotation age for a stand can be calculated. Such criteria as average diameter, minimum diameter, maximum growth rate (height or diameter), a comparison of mean and current or periodic annual increment, and pathological rotation have all been used. It will depend on site, density, composition, management, and utilization requirements, varying generally from 80 to 140 years.

Smithers (1954), using 12 inches as the minimum acceptable diameter at the time of harvest, suggests 120 years for unmanaged and 100 years for managed stands of white and red pine on a good site. Ardenne (1950), on the basis of maximum growth, considers 100 to 110 years for red pine and 130 to 150 years for white pine as reasonable rotation ages. Woolsey and Chapman (1914) and Eyre and Zehngraff (1948) recommend for red pine in the Lake States a first harvest cutting at 80 years and a final cut at 140 years. An increasing incidence of red rot in red pine of 80 years in Manitoba leads Cayford (1956) to suggest

FIGURE 48 - VOLUME INCREMENT CURVES

Red and White Pine



that as a rotation age. Benson (1952), working with red pine in New York, and Gevorkiantz and Zon (1930) with white pine in Wisconsin, also prefer 80 years.

On the basis of some of his graphical data shown herein, McCormack offers a more detailed choice of rotation ages. Poles and piling are an important product of red pine. Considering 50 feet as an acceptable height to start pole production, reference to the dominant height curves of Figure 38 suggests a minimum rotation of 30, 35, 45 and 65 years on site groups I, II, III and IV respectively. Similarly, rotation ages for sawlog production of red or white pine can be calculated from the intersection of the increment curves shown in Figure 48. Maximum board foot production is reached at approximately 80, 110, 120 and 130 years in site groups I, II, III and IV.

ENTOMOLOGY AND PATHOLOGY

This section is contributed by the Forest Biology Division of the Federal Department of Agriculture, and consists of specific accounts, by specialists from the Ontario laboratories of this Division, of the major damage agents on white and red pine.

The principles and many of the details apply generally, but much of the reference is to Ontario conditions. The life history of each important insect and pathogen is briefly recapitulated so that its ecological relationship to the pines can be readily understood and appropriate control measures realized.

Major Pine Insects

A variety of forest insects can cause serious damage to red or white pine. Many are specific, attacking one or the other pine species only; some are not. They individually affect every phase of development from the seed production to the mature tree, and practically every part of the tree.

The loss through their depredations in terms of decreased quantity and quality of harvestable material can be very appreciable, and remedial action may be the primary concern in the management of badly affected stands.

THE WHITE PINE WEEVIL, *Pissodes strobi*, PECK

(C. R. Sullivan)

The white pine weevil has long been a source of concern to both the forester and the entomologist. Peck (1817), who first described the insect, remarked on its abundance and damage and classified it as a major factor limiting the development of straight-boled white pine. The clearing of farm land and its later abandonment resulted in changes in the composition of the forests which favoured weevil multiplication (MacAloney 1943, Maughan 1930). Much of the cleared land was seeded to poorly-stocked white pine and plantations were established on fields and pastures. By about 1925 the many pure stands provided abundant food for the weevil and in many regions the severity of infestation became a factor of major importance in the use of white pine for reforestation.

Injury

The first indication of weevil injury is the appearance of small resin droplets resulting from adult feeding on the upper parts of the previous year's terminal shoot. This feeding seldom causes the death of the shoot. Leader mortality is

caused by larval feeding in the inner bark and may easily be detected by the characteristic drooping and discoloration of the new terminal growth later in the season (Figure 49). Two or more year's growth is destroyed. When this occurs, a single lateral may assume leadership with the result that the tree often contains a permanent crook (Figure 50). Sometimes, two or more laterals may compete for the leadership, and the subsequent forking renders the tree commercially useless. Repeated attacks result in multiple-top shrubs of no value (Figure 51).

The first attack of the weevil generally occurs when the trees are about 5 years old. The infestation continues during the next 10 to 15 years, the weevil showing a decided preference for the most vigorous, dominant trees with thick leaders. Repeated attacks on such trees reduce their vigour and height growth so that the co-dominant trees are released and subsequently heavily attacked.

Life History and Habits

In 1907 Hopkins described the general life history of the weevil. Since that time, many publications have appeared that have materially added to our knowledge of the conditions under which this insect successfully completes development and survives hibernation.

The insect has one generation each year. It hibernates as an adult in the litter, commonly at the base of the tree on which it last fed. Survival during this period is affected by weather conditions. Lack of suitable snow coverage shortly after the insects enter hibernation, followed by a winter of intermittent mild weather, rainfall, and freezing temperatures, causes the death of many adults (MacAloney 1930).

Figure 49. Weevilled white pine leader showing wilted current year's growth.

Figure 50. Crook formed as lateral shoot replaces weevilled leader.

Figure 51. Result of repeated weevilling.

The time and rate of emergence of weevils in the spring is dependent upon exposure and temperature of the hibernation site. Optimum conditions generally occur during April when the maximum daily air temperature exceeds about 60°F. (Sullivan 1959). The insects move to the upper portion of the leading shoot, where they feed, mate, and lay their eggs. Optimum weather conditions for these activities occur on relatively calm days when terminal bark temperatures ranging between 75° and 88°F. are associated with moderately low humidity (Sullivan 1958).

The eggs, which are deposited under the outer layers of the bark, hatch in about two weeks and the larvae arrange themselves in a concentric ring about the leader; thereafter, they systematically move downwards by feeding on the inner bark while leaving the outer layer intact. Pupation occurs within the dead leader, often in the pith (Figure 52), and the new adults emerge during August and September. The new adults are incapable of oviposition until the following spring (Barnes 1928), so their activity in the autumn is limited to feeding. They feed on new and old growth alike until weather conditions become unfavourable. During October, they move to the ground to suitable hibernation sites.

Feeding and oviposition by any one weevil may occur on widely separated trees. Movement from one location to another occurs either by crawling or flying. Flight, however, occurs only when the air temperature is above about 70°F. (Barnes 1928, MacAloney 1930) and usually in the direction of the prevailing winds.

The primary host of the weevil is white pine. Throughout its range, however, the insect has commonly been reported attacking Norway spruce, *Picea abies* (L.) Karst.; Scots pine, *Pinus sylvestris* L.; jack pine, *P. banksiana* Lamb.; and white spruce, *Picea glauca* (Moench) Voss.

Figure 52. Larvae and pupae of white pine weevil in pith.

Recently, Graham and Satterlund (1956) reported that the insect has become adapted to red pine, *P. resinosa* Ait.; however, the degree of weevilling on this and other secondary hosts varies directly with locality and the abundance of the primary host.

Control

Despite heavy losses by the weevil, white pine is still used extensively in reforestation. Consequently, control of the insect is of major importance in the establishment and management of white pine stands.

Natural Control

Weather, through its influence on weevil activity and behaviour, serves to limit the amount of infestation during the active season and unfavourable weather conditions may cause high mortality among hibernating weevils.

Many birds, small mammals, and insect predators and parasites have been listed as biological control agents. Taylor (1928, 1929) estimated that birds destroy about 18 per cent of the weevil population from the time of larval maturity to adult emergence. In this respect, woodpeckers, nuthatches, and chickadees have been mentioned (Felt 1913, Graham 1926, MacAloney 1930). Taylor (1928, 1929) concluded that insect parasites and predators are not of sufficient importance to warrant their being selected for applied biological control of *P. strobi*. He quotes predation by insects as accounting for about 3 per cent of weevil mortality and the percentage effectiveness of all parasites collectively as being about 16 per cent. MacAloney (1930) and Taylor both list the three most important primary parasites as *Eurytoma pissodis* Gir., *Lonchaea corticis* Taylor, and *Microbracon pini* Mues. The first two species are relatively common over the entire range of the weevil.

Direct Control

Various methods of direct control have been tested. These include hand picking of adult weevils, banding of trees, application of chemical sprays, and removal of infested leaders. Intensive methods such as the first two are practical only on ornamental trees as it would be uneconomical to apply them to stands grown for commercial purposes.

Effective spray programs have been recommended with the object of protecting young pine stands until the expense of preventing further attack outweighs the advantage of additional straight bole in the trees (Crosby 1950, Potts *et al.* 1942, Shenefelt 1951, Anon. 1957). Excellent control of the weevil has been obtained using concentrated lead arsenate and DDT sprays applied to the leaders in the spring as soon as the weevils are seen on the leaders. The rate of re-infestation is slow, depending on the locality and extent of bordering infested white pine stands. Normally, effective control is maintained during the succeeding two to four years. As young white pine trees are seldom attacked until they are about 4 feet in height, a program which includes two or more spray applications timed to coincide with re-infestations of about 5 per cent will give satisfactory protection during the period when weevil injury is greatest.

Pruning measures applied in salvable stands have resulted in the development of about 200 to 400 unweevilled butt logs per acre. Briefly, the treatment involves removing all weevilled leaders each year from the time weevilling is first detected until the stand closes (MacAloney 1930, 1943, Maughan 1930). By this time stands of normal density and vigour have usually reached a height of about 17 feet. This treatment serves a two-fold purpose; it keeps the weevil population down and stimulates the substitute leaders to straighten up more rapidly. Subsequent pruning operations involve selecting out the most vigorous trees that have escaped serious weevilling and favour proper spacing, and gradually freeing them as the final crop (Cline and MacAloney 1931, 1933, 1935). The trees selected are generally found in the co-dominant or intermediate classes. Girdling of trees marked for removal results in their death after about two years, thus stimulating growth of the remaining trees. By additional pruning of the lower branches on the remaining trees a greater proportion of clear lumber will be obtained at maturity.

Silvicultural Control

As a result of studies dealing with weevil abundance and damage in natural and planted stands of white pine, recommendations have been made for the purposes of reducing weevil abundance by the development of white pine as an understorey crop and stimulating injured trees to grow straight by the development of densely-stocked stands. There is, however, a loss in annual height growth as a result of maintaining stands under these conditions. In open-grown stands the tendency of the insect to select the tallest trees disrupts the process of natural thinning, thus giving retarded trees an opportunity to become dominant. As Graham (1918) points out, ". . . . this interference with normal development reduces the rate of growth for the stand as a whole." The growth of shaded pine is retarded even when site and density factors are otherwise favourable. This reduction in growth is, however, favoured by foresters in preference to exposing the trees to weevil attack.

Graham (1918) and Pierson (1922) have shown that the incidence of weevil injury is directly related to the density of the stand. Recommendations were made which indicated that a fully-stocked stand of mature trees could be expected if the density ranged between 1,200 and 1,500 trees per acre or more during the early years of growth, and subsequent thinning operations were limited to maintaining a fully-stocked stand according to age-class requirements. Subsequent observations by Colville (1923), however, indicated that the amount of injury seemed to be directly related to the abundance of the insect rather than stand

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Figure 53. Young white pine protected by an overstorey of red oak.

density. Similar observations by MacAloney (1930) showed that in areas of infestation exceeding about 50 per cent, stocking would have to exceed the figure quoted by Graham in stands up to about 15 years of age if a satisfactory number of unweevilled or only slightly weevilled trees were to remain as the final crop. Nevertheless, West (1947) has shown that the amount of injury and incidence of repeated weevilling on individual trees increases as the degree of spacing increases from $4' \times 4'$ to $8' \times 4'$. The same relationship has been reported in stands with spacings ranging from $3' \times 3'$ to $6' \times 6'$ (MacAloney 1930.) However, it may be impractical to space trees closer than $6' \times 6'$ and as severe weevil injury usually occurs at this density, other control measures may prove necessary.

Growth of white pine may be more successful in mixture with other tree species (Belyea 1923, Blackman 1919, Blackman and Ellis 1916, Fisher and Terry 1920, Graham 1926, MacAloney 1930, Pierson 1922). Since weevil feeding and oviposition occur most commonly on fully exposed terminals, decrease in damage to the understorey pine depends almost entirely on cover provided by the accompanying species. Graham (1926) reported that under the average aspen canopy damage is light, and under the average oak canopy damage is reduced to zero. In such natural stands, the pine normally develops in stemwise or groupwise mixtures and while both methods afford protection from the weevil, MacAloney (1930, 1943) reported that damage to the pine terminals by tree whipping in stemwise mixtures may prove as injurious to the form of the tree as weevil injury. Groupwise mixtures where the pine groups occupy areas not exceeding about one-tenth acre are quoted as escaping injury. Larger groupings are susceptible to weevil attack.

Protection has been afforded white pine when mixed with other pines and wherever it occurs in mixture with spruces. However, the accompanying species should be immune from weevil attack and remain as the dominant type until the pine has passed the most susceptible period of weevil attack.

The fact that no consistently effective control measure has yet been determined that is applicable to forest conditions may be the result of inadequate knowledge concerning the effect of tree vigour and stand climate on limitation of attack by the white pine weevil. Although shaded and dense stands of white pine have a better chance of escaping serious injury, very little is known concerning the factor or factors which render the trees less attractive to the weevil. As pointed out by Prebble (1951) the answer to this problem may lie in determining whether or not the white pine weevil is directly affected by the attributes of the young trees, such as leader vigour.

In recent studies of the climate in young stands shaded by oak (Figure 53), terminal bark temperature and atmospheric moisture were found to be less favourable. The results indicate that the criterion for the development of weevil-free stands may be found in the limitations that weather and the physical attributes of the trees impose on weevil behaviour and survival (Belyea and Sullivan 1956, Sullivan 1957).

The control of the white pine weevil by the development of resistant strains of white pine has not been advanced to the stage of testing selected types under field conditions. Since white pine with slender leaders often escapes serious injury, vegetative propagation from unweevilled mature trees is being attempted to determine whether this immunity can be perpetuated.

EUROPEAN PINE SHOOT MOTH, *Rhyacionia buoliana* SCHIFF.

(P. J. Pointing)

The European pine shoot moth (Figure 54), a serious pest of pine plantations in Europe, Asia, and the United States (Cook 1949, Hawley 1935), was first reported in Ontario in 1925 when it was intercepted on pine seedlings imported from Holland. Subsequent investigations in 1926 revealed that it was already established in 45 widely-separated areas along the shores of lakes Erie and Ontario (Heimburger 1951). During subsequent years it gradually spread northward to its present limit, approximated by a line drawn from the southern end of Georgian Bay to Kingston, Ontario, (Sippell, MacDonald and Wallace 1955). Scattered infestations which occasionally occur north of this boundary probably can be traced to the planting of infested nursery stock. Local infestations have also been reported from British Columbia, Quebec, and the Maritime Provinces.

All species of native and exotic pines grown in the province may be attacked by this pest, although red and Scots pine are preferred. Nursery stock, reforested areas, shelter belts, and ornamental plantings may be seriously affected. The damage is most obvious on trees from three to six feet in height. Usually, if a plantation escapes injury until crown closure is complete, it will remain relatively free of injury. If, however, the shoot moth becomes established at or near the time of planting the damage may continue indefinitely. Occasionally, large trees are infested and may serve as population reservoirs.

Injury resulting from the feeding of shoot moth larvae is of three kinds. The first, the browning of the current year's needles, particularly prominent on red pine, results from the feeding of the small larvae early in the summer. When

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Figure 54. Adult European pine shoot moth.

Figure 55. Larvae in a red pine bud.

Figure 56. Pupa case protruding from shoot.

the larvae are numerous the resultant discoloration is conspicuous, although there is little apparent effect on the vigour of the host. Later in the summer and early in the fall larvae enter and hollow out buds. Each larva may destroy from one to several buds. The destruction of the entire bud cluster on a single shoot stimulates the development of latent buds below the injury, and where these become numerous, e.g. on tree leaders, their subsequent development results in a malformation typified by the "witch's broom" and "multiple tips" (Figure 58). The third and most obvious injury is that caused in the spring by the later larval stages. Some buds and developing shoots are completely destroyed, but others may be injured only on one side. The latter often bend at the point of injury and

Figure 57. Crook resulting from early attack.

Figure 58. "Witch's broom".

grow horizontally early in the growing season, then recover slowly and again grow vertically producing a "bayonet top" or "post horn" (Figure 57). Although repeated shoot moth injury results in extreme malformation, the death of the host rarely results.

The shoot moth completes its life cycle in one year. Females (Figure 54), rusty brown in colour, emerge from early June through mid-July, mate, then oviposit in the vicinity of the buds, placing eggs singly, or in small groups on the needle sheaths, on the twig, in the buds and occasionally on the needles of the current year's growth. Rarely are eggs placed on older foliage. Eggs hatch in approximately ten days. On emerging from the egg the larva wanders for some time before spinning a funnel-shaped web between a needle sheath and the twig. From this shelter the larva proceeds to feed on the needles within the sheath. After mining up to six needle pairs, it enters one of the buds, having first spun a web between the bud and adjacent needles. Several buds may be destroyed during the late summer and early fall. In one of the hollowed buds or in the resin-encrusted web the larva, now in the third or fourth stage, passes the winter. When tree growth starts in the spring the larva becomes active, spins a new web and resumes feeding on developing buds consuming from one to several buds and damaging others (Figure 55). Late in May the larva moults for the fifth time, then pupates, usually in a silk-lined chamber in a dry, hollowed bud. The pupal stage lasts for approximately two weeks after which the pupa wriggles until the anterior portion is forced out through a silk-covered opening cut in the bud by the larva before pupation (Figure 56). Within minutes the adult emerges.

The most effective natural control of shoot moth populations has been low minimum temperatures during the winter. The over-wintering larvae succumb to temperatures near $-18°$ F; consequently, planting stock free of shoot moths

planted in areas where winter minima fall below −20°F, should remain uninfested. Native and introduced parasites have, to date, exerted negligible control in Ontario.

Where shoot moth populations and the areas involved are small, pruning is an effective direct control. Infected shoots may be clipped and burned during the latter half of May when the damaged shoots are most obvious and the seasonal insect population is at its lowest level.

Sprays, particularly D.D.T., applied as a fine mist have been effective in controlling shoot moth experimentally (Miller and Neiswanger 1955). The larvae are vulnerable when, after emerging from the eggs, they move to the needles and later to the buds during the summer, or when they emerge from the buds in early spring and wander on exposed foliage before spinning new webs. The large quantities of spray required for effective control restrict this method for practical purposes to individual trees, shelter belts, and small plantations. No practical effective means of controlling shoot moth populations in large plantations has been devised.

LONGHORN BEETLES INFESTING THE WOOD OF PINE

(L. M. Gardiner)

Pine trees weakened or killed by fire or wind, and logs or poles left in the woods during the summer months, are subject to heavy damage by wood-boring beetles. Investigations following the disastrous fire of 1948 on the Mississagi watershed of central Ontario showed that these insects, together with the wood staining fungi that gain entrance largely through their workings, were responsible for serious losses in fire-killed pine within a year of death, the degree of loss being related to tree species, severity of burn injury, and original quality (Gardiner 1957, Prebble and Gardiner 1958). In white pine, lightly injured trees suffered an average value loss of about 14 per cent in low-quality logs to 33 per cent in high-quality logs, whereas losses ranged from 17 per cent to 59 per cent in severely injured trees. In red pine, losses were from about 8 per cent to 18 per cent, there being lighter beetle attack in red pine and less variation in log quality. It is quite probable that losses occurring in logs forming the upper tiers of skidways left in the woods during the summer would be similar to those experienced in the severely burned trees. Woodborer populations, and consequent damage, are much lighter in logs buried within the skidway.

The most destructive insects infesting pine wood belong to the beetle family Cerambycidae, the longhorned beetles, so-called because of the remarkably long antennae of the adults. Over 20 different species are known to attack pine in Eastern Canada, but only a few are of economic importance. The species vary considerably in their habits, but can be classified into two broad categories; the deep-boring species and the shallow-boring species. The deep-boring species, which cause the most serious damage to saw timber, spend a part of their larval lives feeding on the inner bark and surface of the sapwood, and the remainder deep within the wood where they obtain shelter and construct their pupal chambers. The shallow-boring species spend the entire larval period under the bark, with some entering the wood only a short distance to pupate.

The sawyer beetles, *Monochamus notatus* (Drury) and *M. scutellatus* (Say), (Figure 59), are the most destructive in pine. Both species have similar habits and life histories which have been well described (Belyea 1952, Craighead 1923,

Figure 59. Male and female adults of *Monochamus scutellatus* (upper) and *M. notatus* (lower).

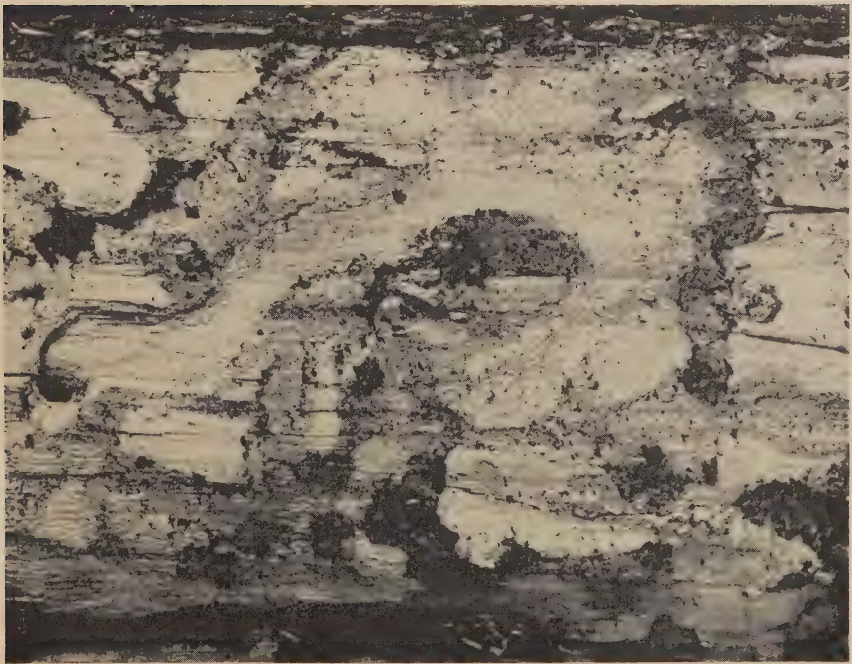

Figure 60. Larval galleries of *M. notatus* in white pine (bark removed), showing larval entrance holes.

Figure 61. *Monochamus* larval tunnel in white pine showing pupal chamber and exit hole.

Figure 62. Damage to twig of jack pine by *Monochamus* beetle.

1950, Simpson 1951). The female chews a slit in the bark and deposits one or more eggs within. The legless, white larvae feed for three or four weeks on the inner bark, deeply scoring the wood surface (Figure 60), then enter the wood and construct a long U-shaped tunnel, the end of which is enlarged to form a pupal chamber (Figure 61). The adult emerges by chewing a circular hole through the remaining wood and bark. Completion of development normally takes two years in Ontario, but adult emergence has been noted from fire-killed trees after only one year. The adults feed extensively on the bark of twigs of most coniferous tree species (Figure 62), but appear to prefer that of the pines. Considerable damage may be done in this way to small trees when the beetles are numerous.

Other deep-boring species occur in pine, but none are responsible for as much damage as the *Monochamus* beetles. One of these, *Asemum atrum* Esch., mines extensively in the sapwood and heartwood, and leaves a network of mines filled with a mixture of fibrous and pellet-like frass. From one to three years are required for completion of development, the insect pupating in the sapwood or bark. The larvae can live in very dry wood and may continue their activities in sawn lumber unless it is kiln-dried. *Xylotrechus sagittatus* Germ. and *X. undulatus* Say, feed under the bark for a time before entering the wood where they may construct extensive mines to a depth of 2 to 3 inches. The galleries are left tightly packed with a fine, floury frass, and are sometimes hard to detect in lumber because of this. Frequently, the mines are restricted to an area within the boundaries of a single annual ring.

Of the shallow-boring types, only *Tetropium cinnamopterum* Kby. enters the wood. Its eggs are laid under the bark scales and the young larvae bore into the inner bark in which they feed. At the end of the feeding period, the larvae enter the wood a short distance, then turn at right angles in the direction of the grain and excavate pupal cells. Development is completed in one year, the adult emerging through the entrance hole made by the larva. The damage caused by this species is slight since it rarely enters the wood deeper than one inch.

All the other shallow-boring species spend the entire larval period between the bark and the wood, doing no direct damage, but permitting the entry of wood staining fungi. *Acmaeops proteus* Kby. is probably the most numerous of all long-horned beetles in the coniferous forests of Eastern Canada. Eggs are laid under bark scales, and the flat, hairy larvae feed on the inner bark, converting it to a mass of coarse frass. After two season's feeding, the larvae drop to the ground and pupate in the soil. *Rhagium inquisitor* (L) commonly attacks the lower trunks of dead and dying pines. A complete description of the life cycle of this insect has been provided by Hess (1920). The larva is easily identified since it is the only pine-inhabiting cerambycid in which the head is wider than the rest of the body. It makes a circular pupal chamber of chips and frass under the bark. *Acanthocinus pusillus* Kby. is closely related to *Monochamus* spp. but it does not enter the wood. One year is required for completion of development, the complete larval period being spent in feeding on the inner bark. Pupation takes place on the surface of wood or in the bark.

Most of the control methods against wood-boring insects have been aimed at preventing attack rather than killing the larvae already under the bark or in the wood. Rapid utilization is the best method of preventing infestation. This is not so important in Eastern Canada where most logging is still conducted during

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the fall and winter months, in which case the logs need not be sawn until the following June. In summer logging operations, which are becoming increasingly prevalent, rapid utilization is essential.

"Hung-up drives" resulting from an early spring thaw sometimes necessitate the storing of logs in the woods during the period when the beetles are active, and some form of control must be practised. An effective method is to place the logs in water, but this is not always feasible or desirable. Barking the logs or covering them with balsam brush may be employed. The former is costly and rarely is there enough of the right kind of brush available. To date, the most promising answer to the borer problem seems to be the use of contact and fumigant insecticides. Excellent control of wood-boring insects has been obtained by spraying skidways with appropriate solutions of BHC and DDT in oil (Johnston 1952, Simpson 1951, Blais 1952, 1953). Such solutions have been used with satisfactory result by a number of lumber and pulp and paper firms in Ontario and Quebec, despite the high cost of transporting oil to the spraying sites.

More recently, interest has been shown in the use of 20 per cent gamma isomer BHC emulsifiable concentrate mixed with water from local lakes and streams. The Chemical Control Section of the Forest Biology Division recommends using 1 gallon of concentrate mixed with water to give 100 gallons of spray. This forms a 0.2 per cent gamma isomer spray which should give good results; almost complete protection may be obtained by halving water to obtain a 0.4 per cent gamma isomer spray. The mixture should be applied to skidways early in June before the wood-borer adults are active, and bark surfaces should be thoroughly wetted. An estimate of 1 gallon of spray per thousand f.b.m. of stacked logs may serve as guide in making up the mixture.

PINE BARK BEETLES

(J. B. Thomas)

Bark beetles have not been reported as causing severe damage to stands of mature white and red pine in Ontario and Quebec, although several species infest dead or dying trees, freshly-cut logs, and logging slash of both species. The activity of bark beetles in slash and dead trees is beneficial ecologically, as it prepares the way for the ultimate breakdown of the wood by other insects and wood-destroying organisms. There is, however, a potential danger that populations of some species which ordinarily breed in slash and dead trees may increase following fires or logging operations to the point where they attack and kill adjacent healthy trees. (Chamberlin 1939, Craighead 1950, Swaine 1918, Thomas 1955). The following species might attack healthy trees under such conditions: *Ips pini* (Say), *Orthotomicus caelatus* (Eich.), *Hylurgops pinifex* (Fitch), *Dendroctonus valens* Lec., and *Pityogenes hopkinsi* Sw.

Attacks by *Ips pini* in healthy pine trees have been observed in recent years in Ontario. During the winter of 1948-49 in Dufferin County, white pine cut in a woodlot adjacent to a 20-year-old red pine plantation provided abundant breeding material for bark beetles. In the summer of 1949 living trees infested by *Ips pini* were observed in the plantation, and by 1951 all infested trees had died. The summer of 1949 was an unusually dry one, and examination of the infestation indicated that the severity of attack was influenced by moisture conditions favourable to the development of the beetles, but unfavourable to the vigorous growth of the trees.

Since *Ips pini* is the species which poses the greatest threat to plantations and to mature trees weakened from other causes, a brief outline of the seasonal development of this bettle is presented.

About midway through the developmental period of the first brood, the parent beetles leave the first set of galleries and produce a second brood. If conditions are favourable, a third brood may be produced in the one season by the same parent beetles. The young adults, progeny of the first brood, feed in the bark for a time and may then either remain in the original brood tree until time for hibernation, or attack fresh material and construct feeding galleries or brood galleries. In the latter case a second generation of bark beetles is produced in the one season. Progeny of the second and third broods rarely breed during the same year. Since the best breeding sites are usually occupied by the initial attack, the succeeding brood galleries are generally in less favourable sites in the same area unless new slash, windfalls, or weakened trees are available. It is at this time when the emerging beetles cannot find dead or dying material that living trees may be attacked and killed, particularly in plantations.

On emergence from overwintering, the male beetle makes an entrance through the outer bark of a suitable brood tree and excavates a small nuptial chamber in the inner bark, usually scoring the cambial area slightly. The male is then joined by from three to five females, each of which proceeds to cut a gallery from the nuptial chamber. The eggs are deposited singly in niches cut into both sides of the galleries and packed with boring dust. The female completes one niche, deposits an egg and packs it in solidly, before proceeding to extend the gallery and make the next niche. The eggs hatch in seven to ten days,

Figure 63. Adult and larval mines of *Ips pini* (Say) in white pine bark 20 days after initial attack.

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those nearest the nuptial chamber first, and the larvae mine through the phloem, approximately at right angles to the egg galleries. As the larvae from different galleries begin feeding, they approach each other and are forced to deviate from a straight course. Figure 63 shows a number of egg galleries and larval mines of *Ips pini* in the inner bark of white pine 20 to 25 days after the initial attack. Pupation occurs in a small cell excavated in the bark at the end of the larval mine. The first brood develops in approximately 30 to 35 days from the time the first eggs are laid. Since both adult and larval mining of *Ips pini* and other true bark beetles attacking red and white pine is confined to the inner bark, scoring the sapwood but slightly, these insects do not damage the wood of infested trees or logs. However, the activity of the beetles assists the entrance into the wood of wood-staining fungi which may discolour it to a sufficient depth to result in serious degrade in lumber sawn from infested logs.

A second group of beetles, the ambrosia beetles, or "pinhole borers", usually attack only dying or newly-dead trees, or freshly cut logs. Two species, *Gnathotrichus materiarius* (Fitch) and *Trypodendron lineatum* (Olivier), infest dying red and white pine, as well as stumps, logs, and rarely tops and slash. These beetles attack in the spring about the same time as the bark beetles, the adults boring directly through the bark and into the sapwood. Branch tunnels are cut from the main tunnel and follow the annual growth rings of the tree. The eggs are laid in niches cut in the upper and lower sides of the branch tunnels, and on hatching, the larvae excavate small cradles in the wood at right angles to the tunnel. In these the larvae complete development and pupate. Ambrosia beetles do not eat wood but feed on a fungus which grows on the walls of the tunnels and in the egg cradles, having been introduced into the tunnels by the attacking adults. The sides of the tunnels become blackened with the fungus which spreads into the surrounding sapwood and stains it. Since the fungus requires relatively high moisture conditions for propagation, only those trees and logs in this condition at the time of adult flight are attacked.

Ambrosia beetles damage trees and logs both mechanically and by the staining of the sapwood by the fungus. Both defects cause considerable degrade in the quality of lumber sawn from infested material.

PINE SAWFLIES

(D. R. Wallace)

Although sawflies of at least three families feed on red and white pine, only those of the genera *Diprion* and *Neodiprion* (Ross 1955) of the family Diprionidae (Ross 1951) are of importance. Sawflies derive their name from the habit of the female adult of laying her eggs in a slit in the foliage made with its lance-like ovipositor or "saw". The larvae of diprionid sawflies feed on the foliage. After feeding and growth are completed, the larvae either leave the tree and spin tough, brown cocoons in the litter on the forest floor, or spin their cocoons on the foliage or twigs. Development of the pupa and the adult takes place inside the cocoon, the adult emerging through a hole cut with its mandibles.

Five diprionid sawflies are among the more common defoliators of red and white pine in Ontario: *Neodiprion lecontei* (Fitch), *Neodiprion nanulus nanulus* Schedl, *Neodiprion sertifer* (Geoff.), *Neodiprion pinetum* (Norton), and *Diprion* (*Diprion*) *similis* (Htg.).

Figure 64. *Neodiprion lecontei.* Larvae feeding on red pine.

Figure 65. Plantation red pine tree defoliated by *N. lecontei.*

Neodiprion lecontei, the red-headed pine sawfly (Figure 64), is the most serious sawfly pest of red pine plantations in southeastern Ontario. This native species is rather widely distributed throughout this province, extending as far north as Sault Ste. Marie and Sudbury and occasionally somewhat farther in the more easterly part. It does not seem to be present in the Lake Erie area or in northwestern or northcentral Ontario. Although red pine is the preferred host tree, jack, Scots, and other pines are often attacked as well. Egg laying is restricted almost entirely to the hard pines, but soft pines and other conifers may be defoliated by migrating larvae (Benjamin 1955). Plantation trees up to 5 or 6 inches d.b.h. are most heavily defoliated (Figure 65). A single complete defoliation may kill small trees while less extensive feeding results in decreased growth and often death of the most severely defoliated branches.

So far as is known, this sawfly has only one generation a year. Oviposition occurs mainly in June and early July, although it may continue to the end of the latter month (Daviault 1951). Each female usually lays slightly less than 100 eggs, which hatch in about 25 days. The larvae feed in clusters, completely destroying needles of the previous year's growth. Larval feeding continues throughout the summer, larvae resulting from late oviposition feeding until early October. The winter is passed in the cocoon in the litter.

Neodiprion nanulus nanulus, the red pine sawfly, is a native species which occurs throughout Ontario south to Lake Ontario but appears to be more abundant in the northern and western parts of the province, where it often causes sporadic but heavy defoliation of red and jack pine. It is primarily a defoliator of large, nearly-mature, or mature trees in naturally occurring stands, although trees in plantations are also frequently attacked. There is a single generation a year with the larvae present from June into early August. Cocoons are formed in the ground litter and the adults emerge in September. Oviposition takes place in current year's growth and the eggs overwinter and hatch early the following summer.

Neodiprion sertifer, the European pine sawfly, was first identified in North America in New Jersey in 1937 (Schaffner 1939), although it had apparently been present as early as 1925. The first Canadian record of this species was at Windsor, Ontario, in 1939 (Brown 1939). By 1959 it had become distributed widely in southwestern Ontario almost as far east as Lake Simcoe, and north into the Bruce Peninsula. This species is a pest in Scots pine plantations, and occasionally in red pine plantations, and has become a serious threat to the growing of Christmas trees in southern Ontario. There is one generation per year of this sawfly, the larval feeding period occurring in May and June.

Neodiprion pinetum, the white pine sawfly, has been found sporadically in widely separated localities in Ontario, particularly south of Lake Nipissing, and only rarely in the northern regions. Although white pine is the preferred host, it has been suggested (Atwood and Peck 1943) that this species may also feed on other pines. Only occasional damage to individual or small groups of white pine trees has been reported. There is a single generation a year and the winter is passed in the cocoon in the ground litter.

Diprion (Diprion) similis, the introduced pine sawfly, is a species of European origin which was first found in North America at New Haven, Connecticut, in 1914 (Britton 1915). The first record in Canada was at Oakville, Ontario, in 1931 (Twinn 1934) and it was also found in the Montreal, Quebec, area in 1935.

The known distribution in Ontario in 1954 was an area some 80 miles in diameter centred at Guelph. Scots pine appears to be the preferred host of this insect in Ontario, although records of attack on white pine are known. Craighead (1950) indicated that white and other five-needle pines are the more important food plants of this sawfly, and of five species of pine tested (white, Scots, red, jack, and mugho), Tsao and Hodson (1956) found white pine to be the most suitable host for the introduced pine sawfly from certain Minnesota localities. Trees in nurseries, plantations and ornamental plantings are more frequently attacked than those in natural stands. There is one complete and a partial second generation yearly in Ontario and larvae may be found from July until early October. The winter is passed as a cocoon either on the foliage or in the duff.

All the above sawflies may be successfully controlled through the application of insecticides either from the air or the ground. Economically, they are primarily pests of plantations; hence it is here that such control operations are most feasible. The control of one species, *Neodiprion sertifer*, by the application of a virus spray from air and ground equipment has recently been demonstrated in southwestern Ontario (Bird 1953). Insectan parasites play an important part in controlling *Diprion* (*Diprion*) *similis* in the United States (Craighead 1950). The most commonly found parasite in southern Ontario in recent years has been *Monodontomerus dentipes* (Dalm.), a species introduced from Europe (Raizenne 1957).

THE SARATOGA SPITTLEBUG ON RED PINE

(L. A. Lyons)

Spittlebugs, so-called since the immature stages secrete a frothy liquid about themselves, include several species capable of injuring pines. *Aphrophora parallela* (Say) is sometimes very abundant on white pine in Ontario and Quebec. It occurs also on Scots pine and, to a lesser extent, on other conifers. The nymphs, surrounded by their conspicuous white froth, occur on the twigs in early summer. In July they develop into adults and the characteristic masses of spittle disappear. The most important species feeding on red pine is the Saratoga spittlebug, *Aphrophora saratogensis* (Fitch). This species was described in 1951, but has become prominent only in recent years owing to serious damage to young plantation trees in the Lake States and Ontario.

In contrast to some other species of the genus *Aphrophora*, in which adults and nymphs have the same host, only the adults of *A. saratogensis* feed on red pine. The nymphs feed entirely on ground cover plants, of which more than 30 have been recorded (Anderson 1946). The chief nymphal host is sweet-fern (*Comptonia peregrina* (L.) Coulter), but infestations can develop where this plant is not present.

The Saratoga spittlebug spends the winter as an egg beneath the scales of large red pine buds. Hatching occurs in early and mid-May as the buds are expanding. The minute red and black nymphs drop to the ground and feed on ground plants, forming their spittle masses on the root collar slightly below the litter surface. Young nymphs are capable of feeding on many different hosts, but toward maturity most nymphs feed on a few favoured hosts, especially sweet-fern and *Rubus* spp.

Mature numphs moult to the adult stage in late June or early July, and feeding on red pine begins. The adult spittlebug punctures the new shoot, which

by this time has completed growth, and extracts sap through its sucking mouthparts. Adults are light reddish-brown, and strongly resemble the new shoot in colour. Feeding occurs both on the shoot axis and at needle bases, and in a heavy infestation there may be six or more punctures per square centimetre of shoot surface (Anderson 1947).

Very light spittlebug feeding causes only premature needle drop, possibly due to the adult habit of feeding at needle bases. Heavier damage causes stunting of subsequent shoot and needle growth. When feeding is heavy enough to kill shoots, the injury usually appears first as browning or "flagging" of short lateral shoots near the top of the tree. As attack continues, flagging spreads throughout the tree, generally following a top-to-bottom pattern (Anderson 1947). Repeated heavy attack results in severe distortion of tree form, and eventually in death. Even light spittlebug attack probably retards growth seriously when the trees are growing on a poor site. Investigations in the United States have shown that adult spittlebug feeding greatly reduces the moisture content and water conduction capacity of shoots. Toxic substances introduced by the insect saliva probably contribute to breakdown of tissues in the feeding punctures. After the affected tissues die, resin infiltrating from nearby cortical canals interferes with water conduction. A fungus, *Chilonectria cucurbitula* (Curr.) Sacc., which has been isolated from injured tissues, possibly contributes to the damage (Anderson 1947).

A. saratogensis seems to be widely distributed in Ontario, but has apparently caused serious damage only in young plantation trees near Chalk River.

Infestations of the Saratoga spittlebug have been effectively controlled by the application of sprays containing one per cent DDT in emulsion or suspension (Anderson 1946). The criteria for judging whether an infestation warrants chemical control measures have received considerable attention in the Lake States. Benjamin, Batzer and Ewan (1953) showed that there is an extremely strong correlation in undamaged trees between the ratio of lateral to terminal shoot length of branches and the position of the branch on the tree, or, in other words, that the growth form of normal trees tends to be very regular. Before it is severe enough to cause twig-killing, spittlebug feeding disrupts the tree's growth form. This is detectable in the weaker correlation coefficient, which indicates the necessity for control. More recently, Ewan (1958) has developed a method for predicting Saratoga spittlebug damage that takes into account such variables as average number of nymphs per acre, tree age, tree size and stand density. By knowing the hazard of the predicted level of damage, a decision can be made as to the necessity for chemical control.

Nymphal populations in the Lake States sometimes suffer heavy mortality as a result of low temperatures in May (about 20°F and below) as well as periods of hot dry weather in June; this mortality, when recognized, may eliminate the necessity of scheduled control operations (Ewan 1958).

INSECTS AFFECTING SEED PRODUCTION IN RED PINE

(L. A. Lyons)

In central and southern Ontario the production of red pine seed is seriously reduced by insect damage to maturing cones. The largest cone crops, as well as the heaviest insect damage, occur on large-crowned open-grown trees, and cone insects may reduce seed production by 40 to 100 per cent. The extent of cone damage and seed loss varies greatly due partly to the habit of red pine of produc-

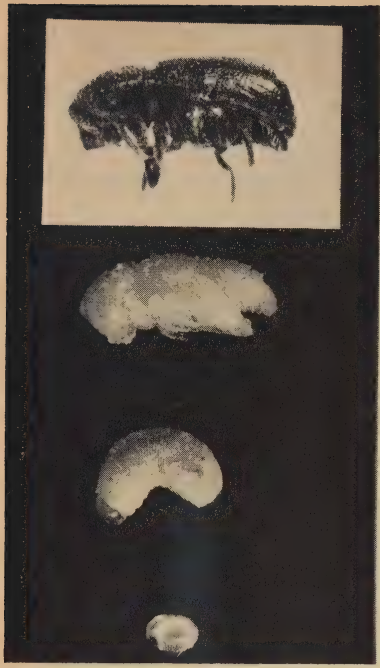

Figure 66. *Conophthorus resinosae.* Adult, pupa, larva, and egg.

Figure 67. Section of red pine cone killed by *C. resinosae*, showing entrance hole.

ing large cone crops only at intervals of several years. The insects responsible for damage likewise vary in abundance; some species are very important in one locality, but insignificant in another. In general, heaviest damage may be expected when cone production remains high enough to permit insects to become abundant. Conversely, an undamaged crop may be expected when cone production increases suddenly after having been low for several years (Lyons 1957).

Almost all direct insect damage occurs during the second, or final year of cone development, although first-year cones die when their supporting shoot is killed by insects or squirrels. The major red pine cone insects in Ontario are the cone beetle, *Conophthorus resinosae* Hopk. (Lyons 1957); cone worms, *Dioryctria disclusa* Hein., *D. abietivorella* (=*abietella*) (Grote), *D. cambiicola zimmermani* (=*cambiicola*) (Grote) (Lyons 1956), *Eucosma monitorana* Hein., and *Laspeyresia toreuta* Grote; and a cecidomyiid fly, *Rubsaamenia* sp. (Lyons 1957). Cones that have been damaged or killed by these insects are often also occupied by a number of predators and scavengers which contribute to natural control of the primary insect and the natural decomposition of the cone.

The cone beetle, *Conophthorus resinosae* (Figure 66), is the most destructive cone insect in most localities. It is closely related to *Conophthorus coniperda* Schwarz, which often destroys large numbers of second-year cones of white pine. The beetles are black, cylindrical, and about 3mm. long. Cone attack begins in late May or early June, and continues until mid or late July. A male and female beetle enter the cone at the base and tunnel along the central axis, where the female deposits eggs in small niches (Figure 67). Each pair of beetles attacks

several cones. Injured cones soon shrink and wither (Figure 68), eventually becoming hard and brown. Larvae pass through two instars and pupate inside the dead cone, and new adults (Figure 69) begin to appear in late July. After leaving the dead cones, new adults bore into small shoots, especially those in shaded portions of the tree, and tunnel into the vegetative buds, where they remain quiescent until the following spring. Bored twigs containing beetles drop to the ground, and may often be collected in large numbers. White pine twigs are occasionally attacked in the same manner. Cone beetles can also complete their life cycle in red pine shoots and in second-year jack pine cones, but probably resort to these only when red pine cones are not available.

C. resinosae has few parasites and predators, but larvae may be killed when the cone is fed upon by other insects.

Dioryctria disclusa generally ranks second to the cone beetle in importance, but appears to be more abundant in southern Ontario than elsewhere in the province. The moths are orange and white with a wing span of about $\frac{3}{4}$ inch. Mature larvae are dark olive-green, with an orange-brown head, and are about $\frac{3}{4}$ inch long. Young larvae feed in staminate cones in the spring until pollen release. Half-grown larvae then tunnel into and excavate second-year cones, leaving a conspicuous hole near the base. Damaged cones seldom produce sound seed. Mature larvae pupate in late June and early July, and adults appear about two weeks later. After mating, female moths deposit eggs singly on needle-less parts of red pine branches. Minute larvae emerge soon afterwards, and hibernate in thin silk cocoons beneath flat pieces of bark. Seven parasitic species have so far been recovered from *D. disclusa* in Ontario (Lyons 1957).

Dioryctria abietivorella, a grey-black moth slightly larger than *D. disclusa*, is usually less important. Young larvae are whitish with black tubercles, and feed as scavengers in cones damaged by other insects. Older larvae vary in colour from purple to brown, and feed in otherwise undamaged cones, tunnelling especially in the upper half, slightly below the surface. Adults appear in mid and late summer. *D. abietella* in Ontario also infests old larval burrows of the European pine shoot moth, and cones of white pine, white spruce, and Norway spruce (Lyons 1957).

Larvae of *Dioryctria zimmermani* tunnel inside and kill the current year's shoots of red pine, some of which may bear young cones. Mature larvae occasionally tunnel into second-year cones to pupate. Shoot damage is prevalent in the Camp Borden region of southern Ontario and on some trees has affected seed production by stimulating the production of short adventitious shoots (Lyons 1957).

Larvae of *Eucosma monitorana* begin to attack cones later than the previously mentioned insects, and have been found only in cones. Infested cones usually lack conspicuous holes, but there may be as few as one to as many as two dozen larvae per cone. The yellowish-white larvae leave the cone in July, and pupate in debris-covered cocoons, probably in the soil. The moths appear the following spring, and are reddish-brown with a wing span of about one-half inch. Infested cones usually wither and turn brown. Only one parasite has been recovered, but many larvae drown in cone resin (Lyons 1957).

Cones infested with *Laspeyresia toreuta*, a silvery-grey moth with black wing markings, do not become discoloured, but the seeds inside are consumed. *L. toreuta* spends the winter as a mature larva inside infested cones, pupates in May and emerges as an adult in June. Some larvae remain dormant in cones another

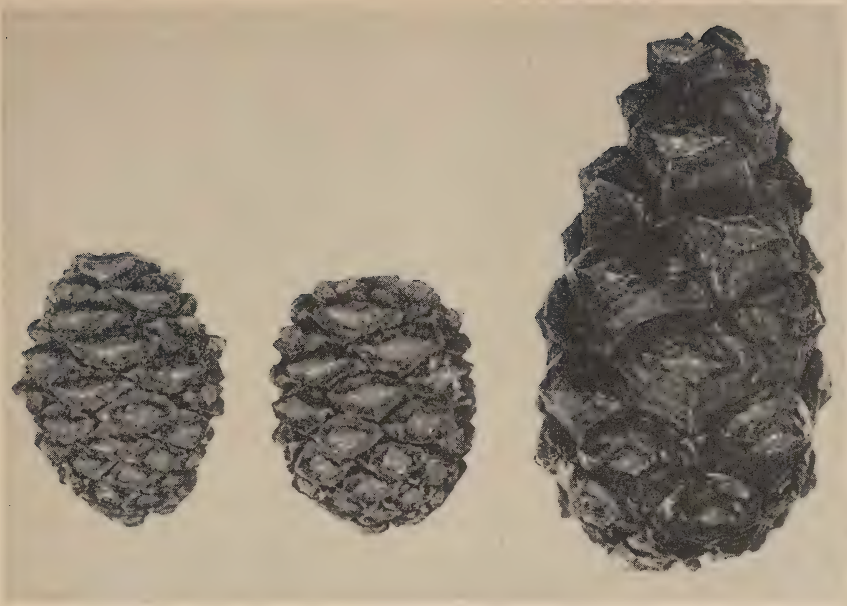

Figure 68. Two cones killed by *C. resinosae* compared with normal cone.

Figure 69. Section of cone killed by *C. resinosae* showing adult and pupa.

full year before pupating. Minute white larvae hatch from eggs deposited on the surface of fully grown cones, bore into the upper part of the cone close to the sutures between upper scales, and then tunnel down the scale to a developing seed. Each larva consumes six to eight seeds before reaching maturity in September. Fully grown larvae tunnel into the woody cone axis where they remain during the winter, and prepare for their eventual escape by extending the tunnel nearly to the surface of the cone (Lyons 1957).

Cones attacked by *Rubsaamenia* sp. contain no castings or debris, but the spaces between scales usually become filled with white flakes of crystallized resin. The legless maggots, which appear in cones in June, are at first whitish, but later become bright reddish-orange. There may be as many as 100 maggots per cone. Feeding occurs between the scales and around developing seeds, which become dry and discoloured. Most maggots leave the cone to pupate in late summer, but some pupate within the cone (Lyons 1957).

Insect damage to red pine cones is usually complete by late July, and injured cones are easily recognized (Lyons 1957). Considerable wasted effort in cone-collecting programs could be avoided through examination of the cones for insect injury in mid-summer.

Major Pine Diseases

(L. T. White)

In the forest, red and white pine are exposed to many destructive diseases. Of the two species, red pine is less subject to attack and serious injury from these diseases. Even heartwood decays, which attain major importance in mature trees of other species are of less economic importance in red pine. White pine, on the other hand, may suffer damage from disease throughout its life. In addition to native diseases, this species is subject to attack by an introduced disease, white pine blister rust, which, in the absence of natural resistance in the host, causes severe damage under certain environmental conditions.

In plantations, red and white pine grow under unnatural conditions that impose increased hazards. Here, other types of injury due to temperature extremes and moisture abnormalities may be followed by increased attacks by destructive organisms.

Among the more important diseases encountered on white and red pine in Ontario are the following:

SEEDLING DISEASES

Damping-off

Damping-off is a term applied to the disease that causes wilting and death of seedlings, particularly coniferous stock. Red and white pine seedlings, among others, are subject to this disease which is caused by one or more soil-inhabiting fungi most commonly belonging to the genera *Rhizoctonia*, *Fusarium*, *Pythium*, and *Phytopthora*. Which of these fungi is important at any given time seems to depend on a number of factors such as site, host, and climatic conditions. Injury may occur either above or below the soil surface. The seed itself may be destroyed or the seedlings may be killed before they emerge from the soil. Infection after emergence causes the seedlings to wilt completely or to wilt at ground level and fall over, Figure 70(1). Under favouring conditions these fungi can cause severe damage.

Figure 70

(1) Red pine seedlings in the Provincial Forest Nursery at Orono, Ontario. "Damping-off" fungi have attacked susceptible seedlings as they emerge from the soil.

(2) Fruit bodies (aecia) of a needle rust caused by *Coleosporium asterum* on needles of red pine.

(3) White pine blister rust—white pine seedling, 1 incn d.b.h., with basal canker centered on a branch now broken off, from which infection entered the trunk. The canker has been chewed by rodents.

(4) White pine trees heavily damaged with white pine blister rust. Dead tops have resulted from complete girdling of the trunks. The tree in the foreground is 18 inches d.b.h., with a 30-foot dead top.

The heaviest losses from this disease occur in forest nurseries where the stock is grown under crowded unnatural conditions. The severity of the damage varies greatly from year to year, depending, in part, upon climatic conditions during the critical period of seedling growth. High humidity favors the development of this disease. Since extensive reforestation programs require large numbers of seedlings, serious economic losses are incurred in increased expenditures for seed and sowing of additional beds to compensate for the loss of stock through disease. Further financial loss often occurs when production quotas are disrupted by damping-off epidemics.

Methods that provide adequate control at one time or place may fail at other times and places. It is evident that, in many cases, the invasion of the nursery by parasites is a manifestation of exhausted fertility, unsuitable fertilization methods, and the building up of large numbers of adverse soil microorganisms. Skillful management of the nursery soil and its multitude of microorganisms, therefore, appears to be a first requirement in the protection of seedlings from this disease. In some instances, the use of suitable composts and the introduction of organic matter, using forest duff from coniferous and hardwood stands, together with direct inoculation with mycorrhizal fungi and other forest soil microflora have markedly reduced disease losses and at the same time produced healthier, more vigorous seedlings (White 1953).

The use of chemicals has in some situations afforded a high measure of protection, though it is apparent that these substances must be used with the greatest caution. Seedlings, particularly of red pine, show an increasing resistance to damping-off in soils which are slightly acid. The addition of peat moss, aluminum sulphate, or ferrous sulphate to produce a pH value of from 5.5 to 6.0 has been found effective in reducing outbreaks of this disease (Cockerill 1954, Morrison 1951, Vaartaja 1954). Recently, the pelletting of seeds with some of the newly developed chemicals, such as thiram (tetramethylthiuram disulphide), captan (N-Trichloromethylthiotetrahydrophthalimide), and others, in a methyl cellulose base has proved to be an effective control measure. (Berbee *et al.* 1953, Cockerill 1955, Richardson 1954).

Other Seedling Diseases

Although damping-off causes the greatest losses in coniferous nurseries, several other disorders may cause concern from time to time.

Snow blight, a disease in which the needles turn brown and exhibit many small black spots soon after the snow melts in the spring, is caused by the fungus *Phacidium infestans* Karst. The injury appears first on the foliage under the snow in the spring and spreads to adjacent seedlings during the following winter. The damaged, discolored seedlings appear in sharp contrast to green healthy plants. This disease is common on nursery stock of red and white pine, and is occasionally severe in some nurseries.

Seedlings are particularly susceptible to many diseases caused by physiogenic agencies, especially soil deficiencies and unfavorable weather conditions. Among the most important of these are injuries caused by frost and drought. A disease of older nursery stock and young trees termed "basal stem girdle" is ascribed to excessive temperatures of the surface soils; this disease has been attributed to the fungus *Pestalozzia hartigii* Tub.

FOLIAGE DISEASES

Needle Blight of White Pine

This disease of white pine has caused considerable alarm during the last 50 years. At the turn of the century it was reported that large numbers of white pine in the Timagami Forest Reserve in Ontario suddenly and inexplicably developed reddish-coloured foliage subsequent to the period of leaf development each year (Faull 1920). The tops of these trees stood out in sharp contrast to the green crowns of healthy, neighboring trees. It is now believed that this abnormal

condition occurs throughout the entire range of this species in Ontario, Quebec, and the Northeast, Central, and Lake States (Eggertson 1949, Spaulding and Hansbrough 1943, Walker 1946).

Needle blight affects trees of all ages from the seedling stage to maturity. Blighted trees occur sporadically throughout the stand on a wide variety of soils and site types. Diseased and healthy trees frequently are found side by side with intermingling roots and branches. In a single tree discoloured foliage may be uniform throughout the crown or, commonly, portions of the tree only may be affected.

Although the disease affects only the new needles of susceptible trees, the new foliage on affected trees may escape injury in certain years. It has been found that semi-mature needle tissue, about four weeks old, is susceptible to the initial onset of foliage injury. First symptoms to appear are faint, pinkish spots in areas of semi-mature tissue on the stomatal faces of the needles. These spots develop into orange-red bands which then spread outward to the needle tips within a few days. An onset early in the summer ultimately affects very little of the needle's length, whereas a later onset, when the new foliage is almost fully grown, affects a greater proportion of the needle (Linzon 1959). Older foliage which has been blighted in previous years is often shed prematurely.

Affected trees make less height and diameter growth than healthy trees. Foliage and leader growth are arrested approximately two weeks earlier than on healthy trees growing under similar conditions. Trees affected by needle blight for several years in succession bear progressively weaker foliage, which in extreme cases is composed only of dwarfed needles of the current year. This condition leads to the early death of the trees (Linzon 1958A).

The symptoms of the disease have suggested that a lack of balance between the requirement of the crown and the capacity of the roots to provide these needs might be due to the presence of a virus. Virus diseases are usually easily transmitted through the use of grafting techniques, but grafting blighted scions to healthy trees or binding together freshly abraded branches of healthy and diseased trees has failed to transmit needle blight. Furthermore, no fungus, isolated from leaves or roots of blighted trees and employed as inoculum for infection studies, has caused symptoms of needle blight to appear in healthy white pine. Several fungi, which are readily isolated from recently blighted needles, appear to be secondary saprophytes. No relationship was found between needle blight and heartwood decay in the commercial portions of stems of white pines (Linzon 1958B). It is known that the feeding roots of white pine normally exhibit abundant mycorrhiza, but in blighted trees these organs are usually sparse or lacking. This suggests that the supply of nutrients is deficient in blighted trees.

In any area, the majority of affected white pine suffer foliage injury at approximately the same time during the summer. The annual incidence of the disease, moreover, fluctuates uniformly on widely separated areas within the same locality. It is apparent, therefore, that local weather strongly influences the appearance of foliar symptoms on susceptible trees. Each major outbreak of the foliar symptoms in an area occurs after a period of wet weather followed suddenly by a continuous sunny period (Linzon 1959).

Several features in the occurrence and nature of white pine needle blight indicate that the disease is controlled genetically. It has been suggested that a

combination of the following factors will result in the appearance of the foliar symptoms of needle blight: (a) inherently susceptible white pines, (b) foliage containing semi-mature tissues, and (c) adverse climatic conditions (Linzon 1959).

Fume Injury

Damage due to atmospheric pollution may occur wherever trees grow in the vicinity of industrial plants which release quantities of toxic gases. Sulphur dioxide, fluorine, hydrochloric acid, or chlorine released by industry, or gasses escaping from leaking mains, are important in this respect. Gas enters through the stomata, or, occasionally in immature tissue, directly through epidermal walls. Many factors, including time of day, season of the year, air humidity, soil moisture, age of tissues, and others, determine the rate of absorption. Generally, plants are not affected during the night or the dormant season (Setterstrom and Zimmerman 1939).

The presence of high concentrations of gas induces a marked shrinkage of the mesophyll cells of the leaf. This shrinkage precedes the appearance of visible external symptoms. Visible fume injury symptoms may appear anywhere on a coniferous needle. The reaction of the leaf to a concentration of gas may be acute; rapid absorption of high concentrations of gas results in the destruction of chlorophyll and produces bright orange-red areas. When a lower accumulation of gas occurs, there is a partial destruction of chlorophyll and the leaves develop a yellow-green color. During the growing season it may be difficult to distinguish between the injury caused by fumes and that due to other causes such as needle blight, winter injury, drought, and leaf fungi.

Although white pine appears to be fairly susceptible to damage from fumes, there is a wide range of susceptibility within the species which cannot be completely explained by differences in crown class, density of foliage, or environmental variations. Red pine is more resistant to fume damage than white pine (Linzon 1950, 1958C). The strength of noxious gas necessary to affect the foliage of a tree is usually very small. Exposure to concentrations of sulphur dioxide higher than 0.40 parts per million for sufficiently long periods during the growing season may be toxic to trees, although lower concentrations, up to 0.25 parts per million, are seldom harmful. On the contrary, the occurrence of sulphur dioxide in very low concentrations may be beneficial to white and red pine growing on sulphur-deficient soils (Katz *et al.* 1939). Severe sulphur fume injury may result in the killing of leaves. Successive defoliation during several years results in a gradual decrease in width of annual rings and finally in the death of the tree. Fume injury to leaves and the resulting damage to trees are most severe in the immediate vicinity of the source of fumes and decrease with increasing distance from the source (Linzon 1958C).

Prevention of fume injury is possible through the elimination of the toxic substances in fumes or by the reduction in concentration of gas below the injury level. Abatement measures include the building of tall stacks, superheating gases in stacks, humidification of gases by water sprays, neutralizing acid gases with suitable bases, or a recovery of gas for the manufacture of by-products.

Other Foliage Diseases

The amount of damage due to other foliage diseases of these species is not, as a rule, severe. Certain diseases, however, such as the foliage rust of red pine are serious in limited areas practically every year.

The needle rust fungus, *Coleosporium asterum* (Diet.) Syd., is widespread in occurrence on red pine, being most common in plantations. Most injury occurs on the lower branches. The aecial stage of the rust, characterized by the production of orange-yellow blisters on the needles, Figure 70(2), is very noticeable in late spring or early summer. These blisters contain a powdery spore mass. When mature, the blisters burst and spores are carried by the wind for a long distance. These spores do not infect other pines but must reach the alternate host of the rust, namely composites (especially aster), to start their growth. The alternate host plants, which are widely distributed in the province, are extensively infected and in turn bear pustules that produce spores which may infect red pine needles.

The needle cast fungus, *Lophodermium pinastri* (Schrad. ex Fr.) Chev., occurs on red pine of all ages throughout the range of the species. The most conspicuous symptom of needle cast disease is a red or brown discoloration of the foliage which may later turn to grey. Needle cast symptoms appear irregularly, involving only a portion of the needle in some cases and leaving healthy needles intermingled with diseased. Needle cast disease is most common on trees of low vigor, being especially severe in plantations with excessive exposure to wind. It has been recorded on white pine, but has so far been of little consequence on that species. Needle casts caused by *Hypoderma desmazierii* Duby on red and white pines and *Bifusella linearis* (Pk.) Höhn and *Lophodermium nitens* Darker on white pine occur quite frequently, but have not seriously interfered with the health of these species.

Needle blight of planted red pine in Ontario, resulting in considerable defoliation, is caused by *Pullularia pullulans* (de Bary) Berkh. in association with a gall midge which alone may be responsible for late fall browning.

Various physiogenic factors usually cause the browning and death of a limited proportion of the foliage of red and white pines annually. Drought, frost, and winter-drying cause considerable injury during some seasons.

The increased use of chemicals and herbicides to control dust and to destroy weeds and woody shrubs along highways and right of ways has resulted in injury to roadside and other plantings. Calcium choride used to settle dust causes injury when dissolved in run-off water which reaches tree roots. The drift of herbicidal sprays (2, 4-D; 2, 4, 5-T, singly or in mixture) to the leaves of desirable trees may result in serious damage. Pine needles turn a bright red and parts of the crowns of trees of all sizes show the effects. Partial defoliation may take place, but death is not usual unless the injury occurs during several successive growing seasons.

STEM DISEASES

White Pine Blister Rust

Blister rust, a disease which is fatal to white pine, is caused by the fungus, *Cronartium ribicola* Fischer. The fungus completes its life cycle by growing upon the leaves of currant or gooseberry bushes (*Ribes* spp.). It is transmitted by means of spores which are distributed by air currents. Infection of pine takes place during the late summer or fall through the needles; from there the fungus grows into the bark of the twig, and finally into the branch and stem. After about $3\frac{1}{2}$ years the affected part of the branch or stem swells and develops a yellowish discoloration at the advancing edges of the affected area. Conspicuous

orange-coloured blisters are formed on this canker during May and June, Figure 70(3). The blisters, when mature, burst and release millions of minute spores which are carried by the wind to infect *Ribes* leaves. Each year after the spores have been distributed, the blisters disappear and the bark dies at that point. The fungus, unable to live on dead tissue, spreads into the surrounding healthy bark.

On the leaves of *Ribes*, the fungus first produces spores which infect other *Ribes* bushes, and later, spores which infect white pine. Because the latter are very delicate and cannot retain their ability to infect pine needles unless temperatures and humidity remain within narrow critical limits, rust can only spread from *Ribes* to pines over short distances. The disease tends to advance in waves since environmental conditions favourable to the production and germination of spores occur infrequently over wide areas.

Although believed to be of Asiatic origin, blister rust was introduced into North America on white pine nursery stock imported from German and French nurseries. The first authentic report of the disease on native white pine in North America was from New England in 1909, although infection of its alternate host, *Ribes*, had been reported three years earlier. In Canada it was first discovered at Guelph, Ontario, in 1914. Since then, it has spread throughout the pine forests of Quebec, New Brunswick, Nova Scotia, Prince Edward Island, and British Columbia (McCallum 1929). Later, it was also recorded from Newfoundland, Manitoba, and Alberta.

Blister rust is especially destructive to seedlings and saplings which, when infected, are killed rapidly. Larger trees succumb more slowly. Infections on the trunk cause death of the entire tree or the top. Death and deterioration of upper portions of the trees, Figure 70(4), may limit the productive capacity of mature stands.

In Ontario, rust conditions are far from uniform. In parts of the northern pine region, for historical and geographic reasons, the disease only recently has become established. Here, having established itself locally on the pine host, it may be expected to intensify wherever *Ribes* is found. Although the rate of infection is still low in general and few large trees have been killed (Eggertson 1949, Haddow *et al.* 1952, 1953, 1955) the disease presents an increasing hazard in newly established stands.

Farther south, in areas which supported the principal production of pine a few decades ago, the disease has been present long enough to cause appreciable damage. Here the picture is very different from that in the old stands in the north where the rust has been established only a few years. Where *Ribes* are numerous in these young forests there is a high rate of infection of pine, and a large number of dead and dying trees is to be found (Haddow *et al.* 1952, 1953, 1955). Salvage of such timber already merits close attention in many stands; and it is clear that the protection of these woods is an important and continuing problem.

In the farm woodlots and other wooded areas of southern Ontario, white pine has largely disappeared except where favoured by planting and care. Blister rust conditions vary from place to place, principally according to the numbers of *Ribes*. Thus, in the pine-oak areas of Norfolk County, which usually harbor very few *Ribes*, rust on pine has remained at a very low level for 40 years. In Simcoe County a considerable mortality has occurred (Haddow *et al.* 1953).

Most plantations of white pine in southern Ontario have suffered little from blister rust. Here, the young and middle-aged plantations are self-protecting against the disease because of natural *Ribes* eradication. Blister rust is a severe

threat only when these plantations are located close to natural hardwood stands where *Ribes* are present. White pine blister rust may be expected to be a threat to older plantations which, under certain management practices, may lack a closed crown cover for an extended period (Cafley 1958).

In northwestern Ontario, where white pine makes up a relatively small proportion of the total timber volume, a brief survey revealed more trees infected with blister rust in the Port Arthur District than in the Fort Frances District. The high rate of infection in the Pigeon River area, despite the fact that no rust-killed trees were seen, indicates that the epidemic is still in an early phase, but that the stands are particularly susceptible and will ultimately suffer severe mortality (Haddow and Hill 1955).

Control of white pine blister rust by the removal of *Ribes* is based on the fact that the fungus can spread only a relatively short distance from *Ribes* to pines. Removal of *Ribes* may be accomplished by digging and pulling by hand or through the use of chemicals and herbicides. Spraying of foliage and stems, basal stem application, and cut-surface treatment of individual root crowns are the principal methods now in use. 2, 4-D and 2, 4, 5-T are considered the cheapest and most effective chemicals for this purpose. Control may be materially aided by silvicultural practices designed to create environmental conditions that suppress the alternate host.

In establishing new plantings of white pine consideration should be given to the fact that a much greater growth of white pine on a good site may more than compensate for the higher cost of *Ribes* eradication on that site. However, while it may be good business to plant white pine on a good site and do the necessary control work rather than on a less favorable site on which *Ribes* are scarce, permanent *Ribes* sites such as swamps where *Ribes* are extremely abundant, and certain hardwood types, should be avoided.

Pruning selected crop trees in young white pine stands has been undertaken in areas where the disease is not aggressive and its spread may be slowed through removal of canker-bearing branches. This practice not only has the advantage of saving crop trees by removing infections but also improves the quality of the lumber produced.

An antibiotic, acti-dione, in a fuel oil carrier has been used as a damage-prevention measure in pole-sized stands of western white pine infected with blister rust before *Ribes* eradication was undertaken. The fungus appears to have been killed in a high percentage of cases in which a basal-stem treatment was applied. Preliminary reports of tests of this treatment in Ontario and the eastern United States, using slightly higher concentrations of the active ingredient than were applied to the thinner-barked western white pine, suggest that it also may be effective in preventing damage to reproduction and pole-sized eastern white pine.

The development of strains of white pine resistant to blister rust has been undertaken as a long-term method of controlling the disease. The time required in selecting and breeding pines resistant to the disease is a major limitation in this procedure. However, in Ontario and elsewhere, seeds and scions have been obtained from trees that have survived for many years in areas of high infection and the resulting seedlings and grafted stock have been tested for resistance by inoculations. Several of these sources apparently do generate trees that are blister rust resistant both to artificial inoculations and under exposure in the

forest. It appears, from studies in Wisconsin and Ontario, that the material obtained to date has yielded susceptible offspring when crossed with unselected stock and that resistance must, therefore, be carried by recessive genes. Attempts are being made to cross native white pines with other species of 5-needled pines that are resistant to blister rust in order to introduce, if possible, dominant genes into native white pines. This subject is dealt with under "Genetics" (page 27).

Other stem diseases

Tympanis canker of pines, caused by *Tympanis* sp., has been recorded on both naturally and artificially regenerated white pine but few trees in any area have been affected. This canker has rarely been noted on red pine.

Dasyscypha agassizii (B. & C.) Sacc. occurs occasionally on blister rust lesions of white pine. Isolated cases of a canker on young white pine trees caused by *Phomopsis* sp. have been recorded. A superficial canker of white pine, caused by *Caliciopsis pinea* Peck has also been noted. The sweet-fern blister rust, caused by *Cronartium comptoniae* Arth. is infrequently found on red pine in Ontario.

Stems of red and white pine are affected to a limited degree each year by a variety of non-infectious agencies including frost, ice and glaze, hail, and lightning, but only occasionally suffer injury of economic consequence.

Decays

Certain fungi can exist in the woody portions of white and red pine where they feed upon, eventually weaken, and in many cases destroy the woody tissues. Two classes of wood-destroying fungi can be distinguished; those which attack and destroy the lignin of the cell walls more readily than the cellulose, and those which confine their activity almost entirely to the cellulose and closely related components. The former cause "white rots" in which the wood is reduced to a fibrous, stringy, or spongy mass, or pockets of white fibers surrounded by firm wood. The color of this decayed wood varies from white to a yellowish-buff. The latter group cause "brown spots" wherein the wood is as a rule transformed into a brown crumbly mass often broken up into cubes separated by shrinkage cracks, the cubes being easily crushed to a powder between the fingers.

The fungi that affect the wood of dead trees may also be divided into two groups based on the portion of the tree attacked. The first group is made up of those present in the heartwood of living trees, and hence are commonly known as heart-rotting fungi. The second group contains those organisms that usually attack only dead trees, and because they practically always initiate infection from the outer sapwood, they are referred to as sap-rotting fungi. Certain fungi belong to both of these groups. The decays of living and dead white and red pine will be considered separately.

Decay in Living Trees

The heartwood-destroying fungi of white and red pine cannot penetrate the bark or survive in the living sapwood tissues of the host. They are able to gain access to the heartwood only by means of a limited number of routes, namely through branch stubs, wounds that expose the heartwood, or by means of dead roots. It is to be expected, then, that as trees become older they will contain increasingly larger amounts of heart rot. This was found to be true in the case of white pine in Ontario, where investigations revealed that in the regions sampled 40 per cent of the trees in the 60-year age class possessed decay compared to 100

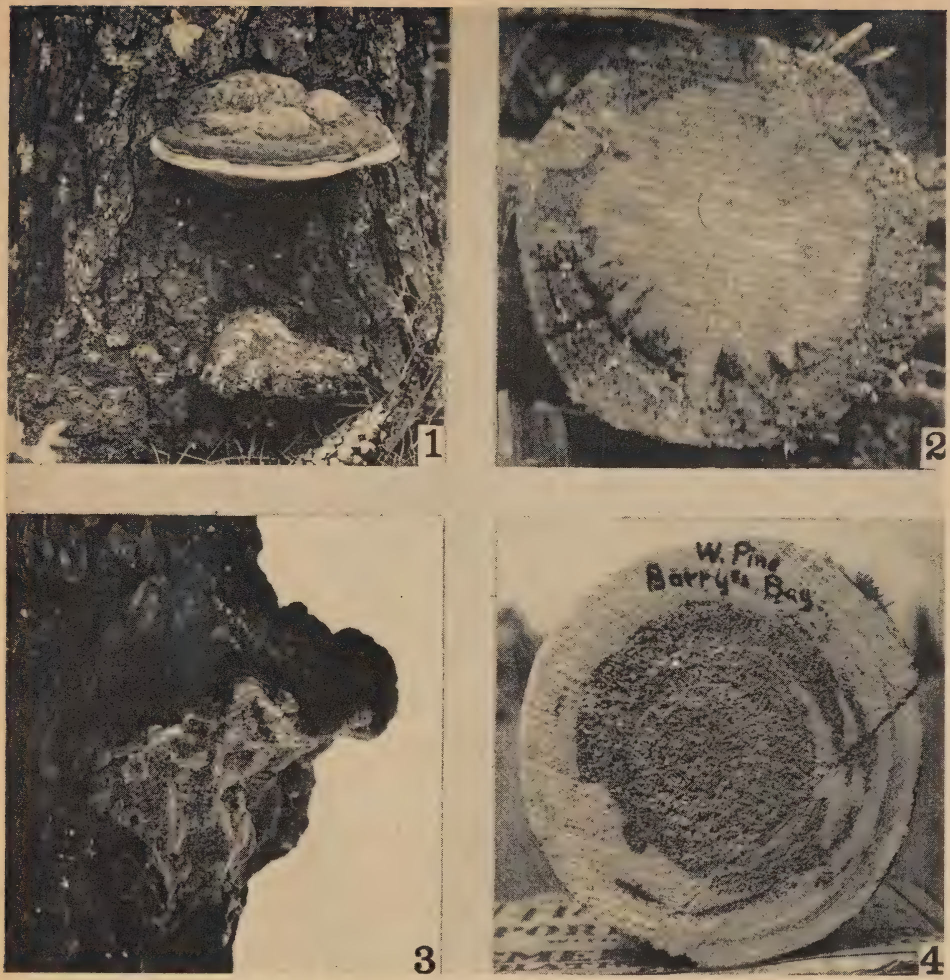

Figure 71

(1) Fruit body of *Fomes pinicola*, the principal cause of "brown cubical" sap rot in dead red and white pines.

(2) Tranverse section of a white pine tree that has been standing dead for four years. Both "white stringy" and "brown cubical" sap rots are evident in the sapwood.

(3) Fruit body of *Fomes pini*, the principal trunk rot in living red and white pine.

(4) Extensive "white pocket" trunk rot caused by *Fomes pini* in a white pine log. This log is a complete cull.

per cent in the 220-year age class; and that the percentage of the gross volume decayed was 4 per cent in the former age class compared to 40 per cent in the latter. The same study revealed that on a basis of the present stocking in mature and overmature stands white pine must be cut in Ontario on a 160 to 170 year rotation to avoid serious losses in merchantable volume due to decay (White 1953).

Over 85 per cent of the decay losses in white pine are due to trunk rots. It must be remembered, however, that butt rots are often indirectly responsible for windthrow and breakage. One fungus, *Fomes pini* (Fr.) Karst., Figure 71(3), is the

most prevalent trunk and butt rot in white pine, and accounts for 90 per cent of the decay losses in this species. It results in a distinctive white pocket rot, the pockets of white fibers being surrounded by relatively firm, reddish wood, Figure 71(4). Practically all of the trunk rot in this species is of this type. Some of the more prevalent fungi that cause butt rot in white pine include *Corticium fuscostratum* Burt, which results in a red stain that ultimately develops into a powdery brown rot; *Corticium galactinum* (Fr.) Burt and *Xeromphalina campanella* (Batsch.ex Fr.) Kühn & Maire, which cause white stringy rots; and two brown cubical rots, *Polyporus schweinitzii* Fr. and *Merulius* sp. (White 1953).

No intensive investigation into heartwood decays of living red pine trees has as yet been made in Ontario. It has been demonstrated, however, that in white and red pine stands of the 150-year age class in the Mississagi region of Ontario the percentage of the gross merchantable volume decayed due to heart rots was over 10 times greater in white pine than in red pine. This indicates that, in general, red pine trees probably possess significantly smaller amounts of decay than white pines. *Polyporus tomentosus* Fr. accounted for the highest proportion of heartwood decays in those trees for which the causal organism was known; it causes a white pocket butt rot. The other principal organisms encountered were *Fomes pini*, *Polyporus schweinitzii*, and *Corticium galactinum*, which apparently cause the same types of rot in red pine as they do in white pine. The "honey mushroom", *Armillaria mellea* (Vahl ex Fr.) Quél., has also been recorded as the cause of the death of many trees in plantations of red pine.

Deterioration of Dead Trees

Once dead, the sapwood, hitherto capable of resisting the invasion of fungi, becomes exceedingly susceptible to attacks of sap-rotting organisms. These fungi gain entrance to the sapwood through the many insect borings and other avenues of entrance in the bark and advance through the wood until, as a rule, the entire tree is infected. Although the progress of these fungi in the heartwood may be fairly slow, the sapwood of pine trees is usually completely decayed within 3 or 4 years after death. The following information on the deterioration of white and red pine was acquired from an investigation into the deterioration of pine stands killed in the Mississagi fire of June, 1948.

A blue stain of the sapwood was the only type of fungal deterioration encountered in those trees examined in the year of the fire, and one year later it was still by far the most prevalent type present. It occurred in every white and red pine tree dissected two years after the fire. About 90 per cent of these trees also revealed patches of brown stain mixed in with the blue stain. Staining fungi derive their nourishment from the cell sap rather than the cell walls, and for this reason are limited to the sapwood and exist only from one to three years following death. They do not affect the strength of the wood to any appreciable extent, although their presence results in lowering of the grade of lumber. Only isolated patches of sap rot were encountered in both red and white pine trees 2 years after death (Basham 1957). By 1952, however, 4 years after the fire, about one-fourth and one-third of the gross merchantable volume of white and red pine trees, respectively, was affected by advanced sap rot, Figure 71(2). At this stage the average depth of penetration of sap rot was 1.5 inches in from the cambium of white pine trees and 2.0 inches in the case of red pine (Basham 1957).

The fungi most frequently isolated from "white" sap rots of these two species were *Polyporus anceps* Peck, *Polyporus abietinus* Dicks. ex Fr., *Peniophora gigan-*

tea (Fr.) Massee, *Corticium galactinum*, and, limited to red pine, *Phlebia radiata* Fr. The "brown" sap rot causal organisms include *Fomes pinicola* (Sw. ex Fr.) Cooke, Figure 71(1), *Coniophora puteana* (Schum. ex Fr.) Karst., *Fomes subroseus* (Weir) Overh., *Poria monticola* Murr., and *Lenzites saepiaria* Wulf. ex Fr., isolated from both species, and *Merulius himantiodes* Fr. found only in red pine trees (Basham 1957).

RESEARCH REQUIREMENTS

There is a wealth of information on white and red pine. Probably in combination these trees have been the object of more research than any other forest type in North America. Still there is much to be learned—and much to be learned about applying the available knowledge. A silvicultural treatment satisfactory in one set of circumstances may be quite inapplicable ecologically or economically in another. Therefore sweeping recommendations for particular methods are inadvisable; rather, flexible silviculture, designed to adapt to a diversity of needs in pine forest management, is advocated. This necessitates a complex research program.

The extensive old-growth stands of pine which provided a thriving lumber industry in Canada until early in the 20th century have largely disappeared and, increasingly, second-growth stands are sustaining the industry. Their proper management requires more intensive silviculture than has previously been practiced. For this reason and for many other reasons given before, increased emphasis on silvicultural research is needed.

Much technical knowledge exists which can be used in forest practice now; much more exists which requires further testing as to scope. Still there remains a multitude of problems requiring research of various intensity. The relative urgency of these problems is largely a matter of viewpoint.

There are pressing practical problems which require immediate applied research. There are long-term fundamental problems, and the sooner they receive attention, the sooner will there be scientifically sound solutions. Some investigations must be timed to take advantage of periodic natural phenomena such as a seed crop, and hence are intermittently urgent. The main research needs of all categories in white and red pine silviculture and management in Canada are reviewed below.

In the field of pine ecology some general relationships are understood but much concrete knowledge of autecology, of the processes behind seedbed preferences, seedling survival and growth, is lacking. Some work is in progress to isolate under artificially controlled conditions the effects of the various main environmental factors in tree development—light, temperature, moisture, nutrients and mycorrhiza. The aim is to find optimum and critical levels in each of these factors for flowering, fruiting, germination and growth, and then to interpret these findings in terms of natural conditions. All such experimentation is long and complex but it is fundamental to the most rational silviculture and therefore more is needed.

The physiology of flowering and fruiting requires research in both pines, particularly red pine. Flower induction holds great promise for silviculture, both as a technique to expedite breeding and as a practical measure in producing more

seed for natural regeneration. Study of the subject has only just begun, and more efforts towards organized observations of natural seed production and experiments with techniques such as ground fertilizing are warranted.

Research in tree breeding is of prime importance with the two pines because of their increasing wide use in artificial reforestation. The main problems are quite different in each species. In eastern white pine resistance is paramount—resistance to blister rust and weevil. The search must continue for more resistant strains among the natural populations of the various white pine species of the world, and among artifical crosses of all likely combinations. Testing, selection, and more testing will be required. Provenance variability is the first problem in red pine breeding. Its nature, whether clinal or ecotypical, needs further study. So does the sterility barrier which prevents the crossing of red pine with closely related species for the improvement of growth, vigor and form. Provenance hybridization needs more trials. A good start in provenance comparison has been made with the establishment of widespread controlled tests. These will require long-term observation.

In applied silviculture, artificial regeneration is at the forefront. The practice of planting white and red pine has outdistanced the research which should precede it, because of the necessity of rehabilitating formerly productive pine lands which have been divested of a natural pine seed source. The testing of site preparation methods for reforesting this derelict forest land is important. The problem is not one of finding new planting techniques but rather the improvement of existing ones and a comparison of their relative efficiency in accordance with species and site.

Direct seeding of pine on forest land has not yet proven fruitful. Many experiments have failed but the cause or causes of failure have usually been evident. Moreover, there have been enough minor successes to show promise. Therefore more trails with more complete control of the variables and with more comparisons of techniques and costs are needed. Intensive small-scale tests would be most feasible at first. Subsequently, large-scale techniques such as aerial broadcast seeding, perhaps in conjunction with site preparation treatments, would deserve attention.

Intermediate cutting in pure or mixed pine stands and plantations has been the subject of a considerable amount of research, and various treatment procedures have been devised. Most of the studies, particularly of spacing, thinning and pruning in plantations, have been carried out in young stands and the conclusions are interim. These investigations must be continued to ensure that forecasted growth trends persist and are consistent. Only when they have been maintained to a full rotation will the answers be certain.

With the increasing emphasis on quality production in white pine sawlogs and red pine polewood, more experimenting is needed in the intensive treatment—thinning plus pruning—of superior stands which are well situated regarding markets. Hand in hand with such a silvicultural study would go economic investigations into costs, quality log utilization, and marketing.

Stand improvement—making the most of what nature and an erratic history has produced—has perhaps not received its due attention. Both pines frequently occur in stands of mixed composition and structure, conditions which generally require improvement. Flexibility in applying techniques is the keynote. Treatments may include any or all of the following: improvement and sanitation

cuttings, release of suppressed pines and other desirable species, seedbed preparation to encourage natural reproduction, and artificial regeneration in poorly stocked stands. Again a comparison of applicable methods and costs is of prime necessity. Continued empirical study of existing representative trials, plus further planned small-scale experiments, would provide a logical approach.

Natural reproduction through harvest cuttings and supplementary methods is, in Canada at least, one of the most important problems in pine silviculture. Nearly all recognized methods have been tried but valid comparisons of their relative applicability according to site, stand history and local economics were seldom possible. Certain methods warrant more testing and evaluation in Canada; for example, shelterwood cutting in pure white pine stands located where intensive silviculture is practical. Generally, a co-ordinated long-term comparison of promising alternative treatment methods on selected representative conditions would provide a sound background for future management.

Techniques supplementary to cutting methods which encourage pine regeneration are being studied but could well receive more attention. Planned ground scarification has shown considerable promise on some conditions, but its scope, relative costs and most effective applications have yet to be determined. The use of chemicals in controlling competition is becoming increasingly common and effective. This field is being fairly thoroughly covered by trails which have application in pine management. Perhaps the most effective and least applied treatment for seedbed preparation and brush control is prescribed burning. Since the white and red pine type in Canada is a natural "fire type", the applicability of controlled burning in its regeneration silviculture is unquestionable. The first problem is to demonstrate its controlled use to a fire-prevention-conscious public, then to establish experiments for the testing of techniques and silvicultural efficiency in comparison with alternative measures.

As the intensity of pine management in Canada increases, so will the need for refinements in stand and site classification and mensuration. General site classifications and corresponding ratings for pine productivity and regeneration capabilities exist but more detailed systems will be required for particular areas and particular objectives. Similarly, in yield prediction, broad empirical classifications exist but there is a need for more controlled specific methods. Work is underway in Ontario to develop normal yield tables for pure white and red pine stands individually, and to assess yield in pine-mixedwood conditions.

Protection is an integral part of pine forestry, and considerable progress is being made against the depredations of insects and diseases. The white pine weevil and blister rust are the main offenders. Research for remedial measures is following several channels—breeding of resistant strains, direct biological and chemical control, and silvicultural adaptations. Much of the work is fundamental and long-term. Meanwhile some methods of control have been worked out and it remains to improve and apply them efficiently.

Thus the search for knowledge from which better methods of pine management may evolve continues, and should go on to the point of diminishing returns. This point will depend to a large extent on future general market trends but the market will be influenced by supply, and a continued supply of good-quality pine products is feasible through efficient silviculture. Without such silviculture there is very likely to be a decline in both supply and quality levels. The aim of this bulletin has been to point out approaches to efficient pine silviculture, and lines requiring more research towards that end.

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APPENDIX I

Tree Species Mentioned and their Botanical Names

Common Species of the Great Lakes–St. Lawrence Forest Region of Canada

Common Name	*Botanical Name*
Aspen, largetooth	*Populus grandidentata* Michx.
trembling	*Populus tremuloides* Michx.
Basswood	*Tilia americana* L.
Beech	*Fagus grandifolia* Ehrh.
Birch, white	*Betula papyrifera* Marsh.
yellow	*Betula lutea* Michx. f.
Cedar, white	*Thuja occidentalis* L.
Cherry, pin	*Prunus pensylvanica* L.f.
Fir, balsam	*Abies balsamea* (L.) Mill.
Hemlock	*Tsuga canadensis* (L.) Carr.
Ironwood	*Ostrya virginiana* (Mill). K. Koch
Maple, red	*Acer rubrum* L.
sugar	*Acer saccharum* Marsh.
Oak, red	*Quercus rubra* L.
Pine, jack	*Pinus banksiana* Lamb.
red	*Pinus resinosa* Ait.
white	*Pinus strobus* L.
Spruce, black	*Picea mariana* (Mill.) BSP.
red	*Picea rubens* Sarg.
white	*Picea glauca* (Moench) Voss

Exotic White Pine Species

Mexican	*Pinus ayacahuite* Ehrenberg.
Himalayan	*P. excelsa* Wall
Himalayan	*P. griffithii* McClel.
Western	*P. monticola* Dougl. ex D. Don
Macedonian	*P. peuce* Griseb.

Exotic Hard Pine Species

Japanese red pine	*Pinus densiflora* Sieb. and Zucc.
Austrian pine	*P. nigra* Arnold var. *austriaca* Aschers and Graebn.
Japanese black pine	*P. thunbergii* Parl.

APPENDIX II

Subordinate Vegetation Commonly Associated with Pine in the Great Lakes–St. Lawrence Forest Region*

Common Name	*Botanical Name*
Alder, green	*Alnus crispa* (Ait.) Pursh
Aster, bigleaf	*Aster macrophyllus* L.
Barren-strawberry	*Waldsteinia fragarioides* (Michx.) Tratt.
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Bedstraw, threeflower	*Galium triflorum* Michx.
Blueberry, low-bush	*Vaccinium angustifolium* Ait.
Blueberry, sour-top	*Vaccinium myrtilloides* Michx.
Bracken	*Pteridium aquilinum* (L.) Kuhn
Bunchberry	*Cornus canadensis* L.
Bush-honeysuckle	*Diervilla lonicera* Mill.
Clintonia, yellow	*Clintonia borealis* (Ait.) Raf.
Clubmoss, bristly	*Lycopodium annotinum* L.
Cow-wheat	*Melampyrum lineare* Desr.
Creeping-cedar	*Lycopodium tristachyum* Pursh
Cucumber-root	*Medeola virginiana* L.
Dicranum, wavy	*Dicranum rugosum* Brid.
Dogbane, spreading	*Apocynum androsaemifolium* L.
Dogtooth-violet	*Erythronium americanum* Ker
Fern, wood	*Dryopteris spinulosa* (O. F. Muell.) Watt
Gold-thread	*Coptis groenlandica* (Oeder) Fern.
Ground-pine	*Lycopodium obscurum* L.
Hazel, beaked	*Corylus cornuta* Marsh.
Honeysuckle, Canada	*Lonicera canadensis* Bartr.
Juniper, dwarf	*Juniperus communis* L. var. *depressa* Pursh.
Labrador-tea	*Ledum groenlandicum* Oeder
Lady-slipper, pink	*Cypripedium acaule* Ait.
Laurel, sheep	*Kalmia angustifolia* L.
Maianthemum	*Maianthemum canadense* Desf.
Maple, mountain	*Acer spicatum* Lam.
Maple, striped	*Acer pensylvanicum* L.
Moss, plume	*Hypnum crista-castrensis* Hedw.
Moss, Schreber's	*Pleurozium schreberi* (BSG.) Mitt.
Mountain-rice, rough	*Oryzopsis asperifolia* Michx.
Mountain-rice, slender	*Oryzopsis pungens* (Torr.) Hitchc.
Partridge-berry	*Mitchella repens* L.
Pearly-everlasting	*Anaphalis margaritacea* (L.) C. B. Clarke
Prince's-pine	*Chimaphilla umbellata* (L). Bart.
Raspberry, dwarf	*Rubus pubescens* Raf.
Raspberry, wild red	*Rubus strigosus* Michx.
Reindeer-moss	*Cladonia rangiferina* (L.) Web.
Rose, prickly	*Rosa acicularis* Lindl.
Sarsaparilla	*Aralia nudicaulis* L.
Sedge, Pennsylvania	*Carex pensylvanica* Lam.

*Derived from pertinent references given in the section on synecology.

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Common Name	*Botanical Name*
Serviceberry, roundleaf......	*Amelanchier sanguinea* (Pursch) DC.
Shinleaf....................	*Pyrola elliptica* Nutt.
Smilacina, zigzag............	*Smilacina racemosa* (L.) Desf.
Soapberry..................	*Shepherdia canadensis* (L.) Nutt.
Solomon's-seal..............	*Polygonatum pubescens* (Willd.)Pursh
Sphagnum..................	*Sphagnum* spp.
Star-flower.................	*Trientalis borealis* Ref.
Sweet-fern..................	*Comptonia peregrina* (L.) Coult.
Trailing-arbutus............	*Epigaea repens* L.
Trillium, purple.............	*Trillium erectum* L.
Trillium, white..............	*Trillium grandiflorum* (Michx.) Salisb.
Twinflower.................	*Linnaea borealis* L.
Twisted-stalk...............	*Streptopus roseus* Michx.
Viburnum, witherod.........	*Viburnum cassinoides* L.
Hobblebush................	*Viburnum alnifolium* Marsh.
Violet, downy yellow........	*Viola pubescens* Ait.
Wintergreen................	*Gaultheria procumbens* L.
Wood-sorel.................	*Oxalis montana* Raf.
Yew, Canada...............	*Taxus canadensis* Marsh.

APPENDIX III

Forest Products Specifications

Tables to indicate the requirements necessary for the different classes or grades of poles, reinforcing stubs, piling, and lumber are included below. No attempt has been made to detail the type or number of defects permissible in each class. A complete list of defects acceptable in each grade along with a definition and description of each type will be found in the publication from which each table was derived and which is shown in the footnote. Canadian Standards Association Specifications are subject to periodic review and occasional revision. The latest revision of the pertinent specification should always be consulted.

Table 1.—*Dimensions of Red Pine Poles*[1]

(Fibre stress 6,600 pounds per square inch)

Class		1	2	3	4	5	6	7	8	9	10
Minimum Circumference at Top (inches)		27	25	23	21	19	17	15	18	15	12
Length of Pole (feet)	* Ground Line Dist. from Butt (feet)	Minimum Circumference at Six (6) Feet from Butt (inches)									
16	$3\frac{1}{2}$	—	—	—	—	22.0	20.5	19.0			
18	$3\frac{1}{2}$	—	—	27.5	25.5	23.5	21.5	20.0			
20	4	32.5	30.5	28.5	26.5	24.5	22.5	21.0			
22	4	34.0	32.0	30.0	27.5	25.5	23.5	22.0			
25	5	36.0	33.5	31.0	29.0	27.0	25.0	23.0			......
30	$5\frac{1}{2}$	39.0	36.5	34.0	31.5	29.0	27.0	25.0		......	
35	6	41.5	38.5	36.0	33.5	31.0	28.5	26.5	......		
40	6	44.0	41.0	38.0	35.5	33.0	30.5	28.0			
45	$6\frac{1}{2}$	46.0	43.0	40.0	37.0	34.5	32.0	29.5			
50	7	48.0	45.0	42.0	39.0	36.0	33.5	31.0			
55	$7\frac{1}{2}$	49.5	46.5	43.5	40.5	37.5	34.5	—			
60	8	51.5	48.0	45.0	42.0	38.5	—	—			
65	$8\frac{1}{2}$	53.0	49.5	46.0	43.0	—	—	—			
70	9	54.5	51.0	47.5	—	—	—	—			

Note: Dotted lines indicate length limits.

[1]Derived from "Specification for the Physical Properties and Preservative Treatment of Jack, Lodgepole and Red Pine Poles and Reinforcing Stubs." (Second edition) Canadian Standards Association C15 (C)—1948.

*The figures in this column are intended solely for use whenever a definition of ground line is necessary in order to apply specification requirements relating to scars, straightness, etc.

Table 2.—*Dimensions of Red Pine Reinforcing Stubs*[1]

(Fibre stress 6,600 pounds per square inch)

Length of Stub (feet)	Minimum Circumference at Six (6) Feet from Butt (inches)			
	Class Z	Class Y	Class X	Class W
10	37.0	32.0	27.0	23.0
11	42.0	36.0	31.0	26.0
13	46.0	40.0	34.0	29.0
15½	47.5	41.5	35.5	—
19½	52.5	45.5	—	—

[1]Derived from "Specification for the Physical Properties and Preservative Treatment of Jack, Lodgepole and Red Pine Poles and Reinforcing Stubs." (Second edition) Canadian Standards Association, C 15 (C)—1948.

Table 3.—*Diameters of Three Classes of Pine Piles*[1]

Length (ft.)	Class A and Class B Piles (These differ in size only)						Class C Piles* (These differ from Classes A and B in size and quality)		
	Class A			Class B					
	Diameter 3 ft. from Butt (in.)		Minimum Diameter of Tip (in.)	Diameter 3 ft. from Butt (in.)		Minimum Diameter of Tip (in.)	Diameter 3 ft. from Butt (in.)		Minimum Diameter of Tip (in.)
	Min.	Max.		Min.	Max.		Min.	Max.	
Under 40	14	18	10	12	20	8	12	20	8
40 to 50 incl.	14	18	9	12	20	7	12	20	6
51 to 70 incl.	14	18	8	13	20	7	12	20	6
71 to 90 incl.	14	20	7	13	20	6	12	20	6
Over 90	14	20	6	13	20	5	12	20	5

[1]Derived from "Standard Specification for Round Timber Piles". Canadian Standards Association, A56—1942.

*In Class C piles, a minimum diameter (at cut-off) of 10 in. may be specified for lengths of 20 ft. and under

APPENDIX IV

Official Grading Rules of Red and White Pine Lumber Adopted by Members of the White Pine Bureau of Canadian Lumbermen's Association[1, 2]

Table 1.—*White Pine* (*Pinus strobus*) *Lumber Grades*

Grade	Dimensions	Main Uses	Requirements
Select Grades			
"C" selects and better	4 ins. and wider 6 to 16 ft. long	High class pattern work, interior and exterior trim, mouldings and framing.	Practically free from defects on one side.
"D" selects	4 ins. or wider 6 to 16 ft. long	Interior and exterior uses similar to "C" selects and better where only one face exposed.	Made up of pieces that carry a finished appearance on one side only, the back of the piece often carrying considerable defects.
Shop or Cut Grades			
No. 1 cuts	6 ins. and wider, 8 to 16 ft. in length in all thicknesses	Pattern stock, sash, doors, panel work.	Boards must be capable of being cut up so that ⅔ or more of the area of the board of cuttings clear on both sides would develop in good-sized sections.
No. 2 cuts	6 ins. and wider, 8 to 16 ft. in length in all thicknesses	As No. 1 cuts in smaller dimensions.	Boards must be capable of cutting out from ½ to ⅔ the area of the board; cuttings clear on both sides, in somewhat smaller sections than permitted in No. 1 cuts but of the same quality.
No. 3 cuts	5 ins. and wider, 6 to 16 ft. in length, in all thicknesses.	Small pattern work, paint doors, sash and toy manufacturing stock.	Boards must be capable of being cut up to produce from ⅓ to ½ the area of the board, cuttings clear on both sides, which may be in short sections.

(Cont'd)

[1]Derived from "Official Grading Rules for White Pine and Red or Norway Pine." White Pine Bureau of Canadian Lumbermen's Association, Eleventh Edition. Published May 1st, 1959.

[2]Comparable standard grading rules for red and white pine in the U.S.A. have been published by the Northeastern Lumber Manufacturer's Association, New York (Anon. 1956).

(*Table 1. cont'd*)

Warehouse and Yard Grades

No. 1 White Pine	4 ins. and wider, 6 to 16 ft. in length in all thicknesses. 5% maximum of 6 ft. lengths allowed in each width.	Exterior and interior finish and trim, cupboards, shelving, veranda flooring, siding.	This grade will permit of sound tight knots whether red or black, size and number to be in proportion to width and length of the piece with other defects taken into consideration. Maximum knots 1 per 2 sq. ft.
No. 2	4 ins., and wider, 6 to 16 ft. in length, in all thicknesses.	High-grade flask lumber and boxes, flooring, joists, fencing, studding, siding, panelling.	Subject to the same general characteristics as No. 1 White Pine, but defects admissible are somewhat larger, more numerous, and of a more pronounced nature.
No. 3 White Pine	4 ins. and wider, 6 to 16 ft. in length, in all thicknesses.	Joists, rafters, concrete forms, subfloors, crating, door cores, boxes, shelving, siding and panelling.	This grade must have one side substantially free of rot. There must not be too heavy a combination of defects. Knots should be expected to remain stable during handling and dressing.
No. 4	4 ins. and wider, 6 to 16 ft. in length, in all thicknesses.	Sheathing, crating and box manufacture.	It is permissible to have in this grade pieces with hard rot in both faces, some soft rot on one face, and a moderate number of other defects.
No. 5 White Pine	4 ins. and wider, 6 to 16 ft. in length, in all thicknesses.	Used where strength is not essential, including construction, temporary buildings, sheathing and crating.	This grade admits all defects known in lumber provided they do not in combination render the piece useless.

Table 2.—*Red Pine (Pinus resinosa) Lumber Grades*

Grade	Dimensions	Main Uses	Requirements
Select Grades			
"D" Select and better.	4 ins. and wider, 6 to 16 ft. long in all thicknesses	Interior and exterior trim, interior finishing, sash, moulding and panel work.	This grade is largely clear one face. The lower face must be No. 2 Red Pine or better.
Warehouse and Yard Grades			
No. 1 Red Pine	4 ins. and wider 6 ft. to 16 ft. long in all thicknesses, with a 5% maximum of 6 ft. lengths allowed in each width.	Interior and exterior finish and trim, panelling, shelving, cupboard work, sills and siding.	This grade will permit of sound tight knots whether red or black, size and number to be in proportion to width and length of the piece, with other defects taken into consideration.
No. 2 Red Pine	4 ins. and wider 6 ft. to 16 ft. long in all thicknesses.	Siding, panelling, lumber boxes, flooring, fencing, crating, sheathing, and other construction use.	Subject to the same general characteristics as No. 1 Red Pine, but defects admissible are somewhat larger, more numerous and of a more pronounced nature.
Merchantable	6 to 16 ft. lengths.		This grade consists of No. 1 and 2 Red Pine in the ratio that these grades develop from individual mill logs.
No. 3 Red Pine	4 ins. and wider 6 ft. to 16 ft. long all thicknesses.	Studding, concrete forms, rafters, joists, framing, planking and timbers in general construction.	This grade must have one side substantially free of rot, will permit sound round or fine tight knots of a limited diameter depending on size of piece. A limited number of defects are allowed but not in a heavy combination.
No. 4	4 ins. and wider 6 ft. to 16 ft. long in all thicknesses.	Moderate priced sheathing, crating and boxes, planking, subflooring.	Permits all defects of No. 3 Red Pine but to a greater degree, plus hard rot on both faces and some soft rot on one face.
No. 5 Red Pine	4 ins. and wider 6 ft. to 16 ft. long in all thicknesses.	Used where strength is not essential, such as temporary buildings, farm construction and crating.	Admits all defects known in lumber provided the piece is strong enough to remain of use.

APPENDIX V

Determination of Form Class

Table 1.*—*Determination of Form-Class, White Pine*

Age Classes

DBH Ins.	25		50						75							100				125							DBH Ins.
	Total Height in Feet																										
	20	30	20	30	40	50	60	70	20	30	40	50	60	70	80	50	60	70	80	50	60	70	80	90	100	110	
	Form-class																										
1	64	68	61	67	72																						1
2	60	66	59	65	70																						2
3	56	63	57	64	69	74	76		58	61																	3
4	52	60	55	62	68	73	75	76	56	59	67	75															4
5	48	58	53	60	67	72	74	75	55	58	66	74	75	75		74	75	75	75	76	77	78	79				5
6			51	59	65	71	73	74	53	57	65	73	74	75		73	75	75	75	74	76	77	78				6
7				57	64	70	71	73		55	64	72	74	74		73	74	74	74	73	75	76	78				7
8				55	63	69	70	72		54	63	71	73	73	71	72	73	74	73	71	74	75	77				8
9				53	62	68	69	71		53	62	70	73	73	70	71	73	73	73	70	73	74	76				9
10				52	60	67	68	70		51	61	69	72	72	69	70	72	72	72	68	72	73	75				10
11				50	59	65	67	69		50	60	68	72	72	69		72	72	72		71	72	74	75			11
12					58	64	66	68			59	67	71	71	68		71	71	71		69	71	73	74			12
13					57	63	65	67			58	67	71	70	67		70	71	70		68	70	72	73			13
14					55	62	64	66			57	66	70	70	67		70	70	70		67	69	71	72	72		14
15					54	61	63	65					70	69	66		69	69	69		66	68	70	71	71		15
16							62	64					69	69	66		68	69	68		65	67	69	70	71		16
17													69	68	65		68	68	68		64	66	68	69	70		17
18													68	67	64		67	68	67		63	65	67	69	69		18
19														67	64		66	67	66			64	66	68	68		19
20																						63	65	67	67	66	20
21																							64	66	67	65	21
22																							63	65	66	64	22
23																							63	64	64	64	23
24																							62	63	64	63	24
25																							61	62	63	63	25
26																							60	61	63	62	26
27																											27
28																											28

Ins.	Age Classes 150								175						200			Ins.
	Total Height in Feet																	
	50	60	70	80	90	100	110	120	70	80	90	100	110	120	100	110	120	
	Form-class																	
8	76	76																8
9	70	74	75	75					75	75								9
10	64	72	73	74					73	74								10
11	58	70	72	73	74	74			72	73								11
12		68	70	72	73	74			70	72								12
13		66	69	71	73	73	72		68	70	72	72	74					13
14		64	68	70	72	73	72		66	69	71	72	74					14
15			67	69	71	72	71			68	70	71	73					15
16			65	68	71	72	71			67	69	71	73					16
17			64	68	70	71	71			66	68	70	72	76	69	74	76	17
18			63	67	69	71	70	67		64	67	70	72	74	68	73	75	18
19			61	66	68	70	70	64		63	66	69	71	72	67	72	74	19
20			60	65	68	70	70	62		62	65	68	71	70	66	71	73	20
21			59	64	67	69	69	60		61	64	68	70	68	64	70	72	21
22				63	66	69	69	57		60	63	67	70	66	63	69	71	22
23				62	65	68	68	55		58	62	67	69	64	62	68	70	23
24				61	65	67	68	52		57	61	66	69	62	60	67	70	24
25				60	64	67	68	50		56	60	66	68	60	59	66	69	25
26				59	63	66	67	48		55	59	65	68	58	58	65	68	26
27				58	63	66	67	45			58	64	67	56	56	64	67	27
28											57	64	67	54	55	63	66	28
29																62	65	29
30																61	64	30

Determination of form-class of trees and stands from diameter, height, and age, for full range of species in Canada.
Table based on data on 776 trees from six localities in Ontario and two in New Brunswick.
Algebraic average difference from original data is −0.3.
*Bedell 1948.

Table 2*—*Determination of Form-Class, Red Pine*

DBH Ins.	Age Classes 50							75				
	Total Height in Feet											
	20	30	40	50	60	70	80	40	50	60	70	80
	Form-class											
1	72	78										
2	67	75										
3	61	72	78	78	79							
4	56	69	76	77	77							
5	50	67	74	75	76	76	76					
6		64	71	74	75	75	75					
7		61	69	72	74	74	74					
8		58	67	71	72	73	73					
9		56	65	69	71	72	72	71	72	73	74	73
10			62	68	70	71	72	68	71	72	73	72
11			60	66	69	70	71	66	70	71	73	71
12								64	69	70	72	71
13								61	67	69	71	70
14								59	66	68	70	70
15								56	65	67	70	69
16									64	66	69	69
17									63	65	68	68
18									62	64	67	68
19									60	63	67	67
20									59	62	65	67
21									58	61	65	66
22												
23												
24												
25												

100					125				150					DBH Ins.
40	50	60	70	80	50	60	70	80	50	60	70	80	90	
														1
														2
														3
														4
														5
														6
														7
														8
73	75	75	76	76	72	75	79	79	77	77	79	80	81	9
70	73	74	75	75	70	74	78	78	74	76	78	79	80	10
66	70	72	74	75	68	72	76	77	70	74	77	79	80	11
63	68	71	73	74	66	71	75	76	67	73	76	78	79	12
59	66	70	72	73	64	69	74	76	64	71	75	77	78	13
56	64	68	71	73	62	68	73	75	61	69	74	76	78	14
52	61	67	70	72	59	66	71	74	57	68	73	75	77	15
	59	65	70	71	57	65	70	73		66	72	74	76	16
	57	64	69	71	55	63	69	72		64	71	73	76	17
	55	62	68	70	53	62	68	72		63	70	73	75	18
	52	61	67	69	51	60	66	71		61	69	72	74	19
	50	60	66	69	48	59	65	70		59	68	71	74	20
	48	58	65	68	46	57	64	69		58	67	70	73	21
										56	66	69	72	22
										54	65	68	72	23
														24
														25

Age Classes

Ins.	175						200				225				Ins.
	Total Height in Feet														
	60	70	80	90	100	110	90	100	110	120	90	100	110	120	
	Form-class														
9	84	82	79	77	77										9
10	83	82	78	77	77										10
11	82	81	78	76	76		77	77	76						11
12	81	80	77	76	76		77	77	76						12
13	79	79	76	75	75		76	76	75						13
14	78	78	76	75	75		76	75	74						14
15	77	77	75	74	74	73	75	75	74						15
16	76	76	75	74	74	73	75	74	73						16
17	75	75	74	74	74	72	74	73	72						17
18	74	74	74	73	73	72	73	73	72						18
19	72	74	73	72	72	71	73	72	71	71	75	74	73	73	19
20	71	73	73	72	72	71	72	71	70	70	74	73	72	72	20
21	70	72	72	71	71	70	71	71	70	69	73	72	71	70	21
22	69	71	72	71	71	70	71	70	69	68	72	71	70	69	22
23	68	70	71	71	71	69	70	69	68	68	72	70	69	68	23
24											71	69	68	67	24
25											70	68	67	66	25

Determination of form-class of trees and stands from diameter, height and age, for full range of species in Canada.
Table based on data from six localities in Ontario, one in Quebec and one in New Brunswick.
Algebraic average difference from original data is -0.2.
Index of total determination is 30%.
*Bedell 1949 (unpublished)